PRODUCTIVITY

OF THE

NATIONAL AIRCRAFT EFFORT

Report of a Committee appointed by the Minister of Technology and the President of the Society of British Aerospace Companies under the Chairmanship of Mr. St. John Elstub.

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INTRODUCTORY STATEMENT BY THE MINISTER OF TECHNOLOGY
AND THE PRESIDENT OF THE SBAC

A Committee to examine the productivity and efficiency of the national aircraft effort was set up by the Minister of Technology and the President of the Society of British Aerospace Companies Limited in March 1967 under the Chairmanship of Mr. St. J. Elstub, in accordance with the recommendation made by the Committee of Enquiry into the Aircraft Industry which sat in 1964-65 under Lord Plowden.

The Report of the Committee is presented herewith. We wish to thank the Chairman and Members of the Committee for the depth of their investigations and the resultant comprehensive assembly of facts contained in the Report. The Report contained a large amount of data which, of necessity, relates to earlier years and because of this the picture presented is not necessarily fully representative of the current situation. As Mr. Elstub indicates in his covering letter, much has been done in recent years by both Government and industry in improving efficiency. The steadily increasing export achievement of the industry, so necessary to the health of the national economy, is indicative of the efficacy of these improvements. Agreement has recently been reached on profit levels and price fixing for Government non-competitive contracts. Discussions have taken place between the Government and industry on the subject of the forward programme of the industry, which now needs to be geared more closely to the expanding world markets. Much else remains to be done.

The Ministry of Technology and the Society of British Aerospace Companies have jointly examined the conclusions and recommendations contained in this Report and we are agreed that we should be guided generally by its contents.

A. WEDGWOOD BENN

J. T. LIDBURY

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MEMORANDUM FROM THE CHAIRMAN

TO THE MINISTER OF TECHNOLOGY AND

THE PRESIDENT OF THE SOCIETY OF BRITISH AEROSPACE COMPANIES

Gentlemen,

I have the honour to present the Report of the Committee which you set up in March 1967 to examine the productivity and efficiency of the national aircraft effort.

I hope that our report will lead to a better understanding of the problems faced by those engaged in the development and production of aircraft and weapons - problems which are in many ways similar to those attending Britain's industrial effort generally.

Many steps have been taken since the Plowden Committee reported, both by industry and the Ministry of Technology to improve efficiency and methods of working. However much remains to be done. Our principal conclusions and recommendations, which are unanimous, are given below:-

PRODUCTIVITY

(1) Measured by value added for each of its employees, the British aircraft industry's productivity is approximately one third that of the American industry. It is not inferior to that of the French industry, its other major competitor.

(paragraphs 40, 45)

(2) By far the most important factor contributing to this "productivity gap" is the small scale of airframe production in Europe. If allowance is made for the difference in production quantities, the ratio of productivity in the United States and Britain is found by several independent methods to be between 1.2 to 1 and 1.5 to 1. This is the true ratio of the "effectiveness" of manpower in the two countries.

(paragraphs 56, 63, 72, 84)

(3) Because British productivity is lower than American, the British industry forfeits the cost advantage which it should gain from its lower wages and salaries, and competing aircraft cost about the same in both countries.

(paragraph 40)

(4) Engines are made in relatively greater numbers than airframes and the manhours required to produce them are about the same in both countries. The British industry therefore gains some of the advantage of its lower wage rates, though it still suffers from smaller total production runs than are usual in the United States.

(paragraphs 56, 84)

TIMESCALE

(5) British projects generally take longer than American, though less time than French from the beginning of design to final certification. The extra time needed is not spread uniformly over the various stages of development. For a number of civil projects the average time from the beginning of design to first flight was in fact less for the British than for the American aircraft. However this advantage was more than offset by the much longer time needed from first flight to certification, and by the greater length of British production cycles.

(paragraphs 117-8, 124)

/EFFECT

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EFFECT OF QUANTITY

(6) The most important step towards improving the industry's productivity would be to make each type of aircraft in larger quantities. Because of the way in which the "learning effect" operates a comparatively small increase in the quantity in which an aircraft is produced can yield a more than proportional increase in its competitiveness. If Britain had the courage to plan the production of its aircraft on a larger scale it would be able to quote prices so much lower than those of its competitors that it should have no difficulty in capturing a large share of the market.

(paragraphs 158, 171-2)

CHOICE OF PROJECTS

(Civil)

(7) As a general principle a new project should be started only when firm prospects of sales are large enough to make its development economic and its selling price competitive. This principle would seem too obvious to require enunciation had it not been so frequently disregarded in the past.

(paragraph 161)

(8) The world market for most types of civil aircraft is expanding but Britain needs to choose new projects which will not only be in wide demand, but which can exploit her strongest areas of technical expertise, the advantage of her lower wages and salaries, and the goodwill earned by earlier aircraft, and for which she has adequate resources to ensure delivery at the right time.

(paragraphs 163-166)

(9) The ratio of R & D cost to the total production cost is a much more important criterion for the selection of a project than their absolute values. The magnitude of R & D cost need not of itself deter Britain from undertaking advanced aircraft projects, provided that the cost estimates and sales forecasts can be relied upon.

(paragraph 189)

(10) Specifications should not be tailored too narrowly to the requirements of a single customer. Sales to the Corporations, while of great value to the industry, do not appear to boost foreign sales.

(paragraphs 176-7)

(Military)

(11) The criteria for choosing civil projects are also important in the selection of military projects, though they will inevitably be modified by other considerations. However the pressure on defence funds makes it very important that the Services should do everything they can to ensure that their equipment has maximum export potential.

(paragraphs 178, 180)

(12) Better project definition and estimating procedures should encourage the Services to place their production orders earlier. Such a display of confidence would help to stimulate foreign orders and the larger total production would reduce domestic prices.

(paragraph 182)

COLLABORATIVE PROJECTS

(13) The attractions of collaboration with other countries and its potential benefits have tended to obscure its disadvantages. These stem mainly from the length of time taken to reach decisions at Government level, and from the fact that considerations of national interest and balancing financial contributions do not necessarily result in the most efficient division of work. It may be that collaboration can only be really effectively achieved if the initiative in seeking opportunities and negotiating partnerships is taken by industry with the support of the Ministry of Technology. The Ministry of Technology should review critically their experience of collaborative projects and seek ways of implementing the policy which are more compatible with efficiency and speedy execution of the work.

(paragraphs 186-192)

/THE

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THE NEED FOR STABILITY

(14) The stability of workload which is essential to the industry's forward planning is unlikely to arise except by chance from the present practice of taking decisions piecemeal on individual projects. In the absence of a clear long term policy for the industry it cannot be expected that the best decisions will be taken or adequate stability achieved. In Chapter 15 we have described a possible approach to the problem of achieving greater stability, which would lead to the appointment of a high-level group from the Government and the industry to work out a plan.

(15) Stability is impossible without reliable cost estimates. The procedures recommended by the Ministry of Aviation's Steering Group on Development Cost Estimating should be generally adopted, particularly its proposals for more thorough project definition studies.

(paragraphs 211-2)

(16) Operational Requirements and Technical Specifications should be defined comprehensively by the time full development begins. The past practice of filling in the details as work proceeded, and even as late as the Final Conference, is not conducive to economy or efficiency.

(paragraphs 214-5, 218)

(17) In the context of a fixed overall defence budget, it is no longer practicable to define the ideal weapon and then estimate what it will cost. It is necessary to start with a figure which can be afforded and then work out what it will buy. Before they authorise full development of a project the Government should determine, with the advice of the main contractors involved, a firm and realistic cost limit which they are prepared to pay for its development and production. The aim should be to contain all increases in cost within this by adjusting the specification and/or the production quantity. The limit should be revised only on account of inflation, or if some unavoidable grave setback is encountered during development.

(paragraphs 222-4)

(18) In order to reduce the risk of a grave setback, future projects should not rely on the simultaneous development of too many novel techniques. More use should be made of proven techniques and components, either developed in advance with general applications in mind ("building blocks") or adapted from previous projects. When the system has been proven in this way, more advanced replacements for older parts of it should be developed where justifiable.

(paragraph 224)

(19) Early in their consultations on a new project the Ministries of Defence, Technology and the main contractor should define the key decisions which will have to be taken and the dates by which they must be taken. Failure to reach decision by the due dates, and its consequences for the timing and cost of the work should be reported to the three parties at a senior level.

(paragraph 228)

PROJECT MANAGEMENT

(20) The amalgamation of technical and financial responsibilities, and of technical and administrative staff in the new Ministry of Technology Project Directorates is proving effective and should be extended where practicable to other areas of the Ministry's aviation work. Project Directors should also be made responsible for the production of at least the initial batches delivered to the Services.

(paragraphs 236-8, 242)

(21) The term of office of individual Project Directors is often shorter than is in the best interest of the project. When career considerations make necessary the posting of a Project Director to other work, more regard should be paid to timing this event so that it occurs at a convenient and logical point in the development programme.

(paragraph 243)

/CONTRACTS

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CONTRACTS

(22) We support the present policy of the Ministry of Technology of employing Incentive Contracts wherever possible. To avoid weakening the discipline of such contracts the Ministry should make the main contractor responsible for as much of the system as they can. They should continue to apply strict criteria in designating equipment to be provided on "Embodiment Loan" terms, and they should demonstrate that there is a significant cost advantage in production before they designate something according to that criterion alone.

(paragraphs 246, 248)

(23) The type of scrutiny which Parliament has recently applied to Government expenditure breeds a very cautious attitude on the part of officials which militates against greater efficiency. A wider interpretation of what constitutes "value for public money" is needed if projects are not to be slowed down and made more costly than necessary.

(paragraphs 252-4)

VALUE ENGINEERING

(24) Companies should increase their efforts to inculcate a greater consciousness of production cost in all parts of their organisation. More staff should be trained in the techniques of Value Engineering and a senior executive should be responsible for ensuring that cost saving proposals are exploited to the full. The Ministry of Technology should encourage the use of Value Engineering when placing its contracts.

(paragraphs 261-5)

FLIGHT TESTING

(25) The calendar time occupied by flight trials should be reduced. More thorough ground testing of systems and components is needed before flight, and more intensive data analysis. The industry should concentrate the staff and equipment required for the latter task at fewer places and work shifts round the clock. The Ministry of Technology should ensure that effort at A & AEE is adequate to match more intensive work by contractors, and to enable acceptance trials to be completed in a shorter time than hitherto.

(paragraphs 280-5)

CAPITAL INVESTMENT

(26) Lack of stability particularly in the work placed on the industry by the Government, coupled with certain contract pricing rules, deters the industry from investing as much as it might in modern capital equipment. We hope that our recommendation (14) and reviews of contract pricing rules currently in progress will lead to ways of reducing this discouragement.

(paragraphs 291-7)

WAGE STRUCTURE

(27) The present wage structure of the industry does not provide the intended incentive to operatives, nor does it exploit the beneficial effects of learning as fully as it might. Management and unions should jointly seek a more appropriate wage structure for the aircraft industry with these aims in view.

(paragraphs 308-9, 313, 316)

QUALITY

(28) The industry should consider making wider use of formal schemes to promote quality-consciousness, presented in a way which will arouse enthusiasm in its employees and avoid conflicting with the aims of payment by results.

(paragraph 104)

INSPECTION

(29) The Ministry of Technology should investigate the possibility of an inspection procedure on the lines of that practised by the Air Registration Board.

(paragraph 325)

/PRODUCTION

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PRODUCTION CONTROL

(30) The ares where the British aircraft industry has in the past lagged furthest behind the American is Production Control. It needs to improve both the quality of its staff and the systems it employs for this task in order to ensure

(a) a smoother flow of work and hence more efficient use of shop floor labour;

(b) a well-balanced load so that delivery dates can be met;

(c) that lead times are shortened so that earlier delivery is possible and that stock and work in progress absorb less capital. If they had kept the value of their inventory as low in relation to their turnover as American firms do, five of the largest British companies could have increased the average return on their capital from 8. 8 per cent to 12. 5 per cent.

(paragrsphs 329, 345)

I am, Gentlemen,
Your obedient servant,

St. John Elstub

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SECTION I - INTRODUCTION

CHAPTER 1 THE WORK OF THE COMMITTEE

1. The Committee was set up jointly by the Ministry of Technology and the Society of British Aerospace Companies in March 1967 in accordance with a recommendation made by the Committee of Inquiry into the Aircraft Industry which sat in 1964-65 under the chairmanship of Lord Plowden. In Chapter 33 of its report (Cmnd. 2853), the Plowden Committee drew some tentative conclusions about the British aircraft industry's efficiency and productivity compared with those of other countries. It recommended that this subject should be examined more fully. The Plowden Committee recognised that the controls which the Government, in order to protect the public purse, impose on work undertaken for them by the industry, may hamper the efficiency with which the job is done. Our terms of reference specifically asked us to examine this aspect. They were as follows:-

I (a) To establish the facts in respect of time scale and costs of major projects, covering both development and production;

(b) to establish the facts about output per man in the industry;

(c) to analyse the factors bearing on further improvements in the productivity and efficiency of the industry;

(d) in respect of (a), (b) and (c) above to make such comparisons as are possible with industries of other countries.

II To ascertain the nature of the technical and financial controls and procedures at present exercised over projects by the Ministry of Technology or its Establishments, and the reasons why the Government impose them; and to establish the effect these have on industrial efficiency and on the ability of the Government to get value for money.

III To set up such sub-committees or working groups as are necessary to carry out the above tasks.

IV In the light of this examination, to recommend measures to improve the competitive efficiency of the industry.

2. Mr. St. John Elstub, Managing Director of Imperial Metal Industries, who was a member of the Plowden Committee, was appointed as Chairman. The Committee comprised:-

(a) Four members from the Ministry of Technology:-

Mr. L. R. Beesly	- Director-General of Aircraft Production
Mr. Handel Davies	- Deputy Controller of Aircraft (Research & Development)
Mr. W. G. Downey	- Under-Secretary, Air C Division
Mr. E. W. G. Haynes	- Under-Secretary, Contracts Division

Mr. D. A. Lovelock took over Mr. Haynes' post in May 1968 and succeeded him as a member of the Committee in the same month.

(b) Four members nominated by the Society of British Aerospace Companies:-

Mr. J. L. Hilton	- Central Staff, The Plessey Company
Mr. F. T. Hinkley	- Commercial Director, Rolls-Royce
Mr. R. L. Lickley	- Assistant Managing Director, Hawker Siddeley Aviation
Mr. F. W. Page	- Chairman & Managing Director, British Aircraft Corporation (Preston Division)

Mr. Hilton retired from the Plessey Company in August 1968, but continued to represent the equipment group of the S.B.A.C. on the Committee.

/(c)

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(c) Two other independent members:-

Professor G. C. Allen - Emeritus Professor of Political Economy in the University of London

Mr. J. H. N. Thompson - Deputy Chairman, John Thompson Ltd.

With the agreement of the S. B. A. C., the Secretariat was provided by the Ministry of Technology.

3. We held the first of our fifty-five meetings on 4th April 1967. We set up a sub-committee on "Value Engineering", which held ten meetings, and an informal working party on Production Control. We appointed two firms of Management Consultants to carry out detailed studies of comparative productivity in the United States and the United Kingdom, and of the effect of the industry's wage structure on its productivity.

4. During its inquiry the Committee visited factories of British Aircraft Corporation, Hawker Siddeley Aviation, Imperial Metal Industries and Rolls-Royce. A group of members visited Sweden to study military aircraft procurement there; another group visited the United States for an exchange of views on British and American productivity and methods in aircraft manufacture, and to study American production facilities. The Committee felt that a similar visit to France was unnecessary, since a considerable body of knowledge of French practice was available to it from experience gained on Anglo-French collaborative projects.

5. We interpreted the scope of our inquiry as embracing the activities of those engaged in the design, development, manufacture and repair of airframes, aero-engines, ancillary equipment for them and guided weapons. In dealing with ancillary equipment we concentrated on that of a mechanical, hydraulic, or electro-mechanical nature rather than purely electronic equipment, although the distinction between them is becoming less and less clear cut. In this area we were additionally constrained by the physical impossibility of covering thoroughly in the time available the activities of a group of manufacturers at once so numerous and so varied in size and product. Although we gave some consideration to guided weapons, we felt we should place the main emphasis of our enquiry on aeroplanes, which constitute almost 90 per cent of the value of the industry's output.

6. The names of individuals and bodies who submitted written evidence to the Committee are listed in Annex A. We also took oral evidence from a number of people listed in Annex B, some of whom also presented written submissions. We are grateful to all those who gave evidence for their interest and co-operation.

7. We are also indebted to the personnel of the companies to which our members from the aircraft industry belong. They devoted considerable time and effort to the preparation of papers and presentations illustrating many aspects of aircraft manufacture. In addition they provided the Consultants with much detailed historical data needed for their studies. A number of other companies in the industry provided information, in some cases in considerable detail, which was of great help in our investigations.

8. Finally we wish to acknowledge the assistance and support which we received from the Ministry of Technology, the Ministry of Defence and the Foreign and Commonwealth Office. Their officers at all levels devoted a great deal of time and care to answering the many questions we put to them and to ensuring that our visits to other countries were of maximum benefit to our inquiry.

9. Mr. H. J. Blanks, of the Ministry of Technology has acted as our secretary for twenty-two months. During the past four months he has been assisted by Mr. R. C. C. Jewell, but for most of the time he has coped single-handed and most efficiently with a considerable administrative load. His knowledge of Ministry of Technology procedures and his analytical ability were of great help to us in sifting the evidence in the early stages and more recently the main task of preparing the report has fallen on him. We are most grateful to him. We should also like to thank Mrs. E. Perrie, of the Ministry of Technology, who has provided most efficient secretarial assistance.

/CHAPTER 2

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CHAPTER 2 THE FORM OF THE REPORT

10. We have tried to cover our terms of reference as fully as possible. In our report, however, we bave not kept to the distinction made in them between the responsibility for productivity of "Industry" and "Government" respectively. Development and production of military aircraft in Britain requires close co-operation between tbem. To an increasing extent this is also true of civil aircraft. Both the industry and the Government have a part to play, and depend upon each other, to ensure that the United Kingdom gets the best value out of projects for the money and effort it puts into them. Hence when discussing a particular problem we msntion all the factors which bear on it. At the same time we try to show quite clearly with whom lies the responsibility for making the improvements we recommend.

11. Our report takes the following form. The next Chapter concludes this introductory section by briefly setting the stage on which our inquiry has taken place. It describes the resources engaged in aeronautical manufacture, their output, the relation of producers to buyers and the changes which have been made in the structure of the industry and its methods since the Plowden Committee reported. In Section II we describe what we have done to measure productivity and in Section III we examine the time taken by various stages of a project. The efforts which the industry has made and is making to improve its efficiency form the subject of Section IV. Section V analyses the comparison of Britain's performance with that of other countries contained in Sections II and III. It also sets out the steps whicb sbould be taken to improve Britain's competitive performance. Section VI summaries our conclusions and recommendations.

/CHAPTER 3

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12. Despite the cancellation of three major projects early in 1965 the resources of the industry have changed little since the time of the Plowden Report. In the ensuing three and a half years total employment in the industry has declined by just over 4 per cent, to 247,000. This figure accounts for about 3 per cent of the total United Kingdom labour force in manufacturing. It is spread among more than three hundred factories. The smallest of them has fewer than 25 employees, the largest more than 20,000.

13. The merger in 1966 of Rolls-Royce and Bristol Siddsley Engines has reduced to four the major groups which provide 64 per cent of the industry's employment. The other three, the British Aircraft Corporation, the Hawker Siddeley Group and Westland Aircraft, are mainly concerned with airframes and guided weapons. The Hawker Siddeley Group has extensive interests outside aviation and Westland Aircraft specialises in helicopters. Handley Page remains independent of these groups. The Government own the majority of shares in Short Brothers and Harland of Belfast, and all the shares of Beagle Aircraft (1968) Ltd., who concentrate on light aeroplanes. A newcomer to the industry is Britten-Norman which is active in the development of hovercraft and light aeroplanes.

14. The remainder of the industry is chiefly engaged either in sub-contract work for the main aircraft and engine firms or in providing them with equipment for use in their products. Such equipment ranges from micro-switches and lamps to a complete undercarriage or the fuel control system for an engine.

15. The resources contributed by the Government are concentratsd in the Aviation and Research Groups of the Ministry of Technology. Nearly 30,000 people of all grades in the Department are concerned with aerospace work. About 60 per cent of them are employed in Aviation Research and Development Establishments such as the Royal Aircraft Establishment, the National Gas Turbine Establishment, the Royal Radar Establishment and the Aircraft and Armament Experimental Establishment. They undertake fundamental and applied research, monitor and advise on the progress of development by industry and test the resulting aircraft and engines. Most of the remainder, who are based at headquarters, are engaged in the planning and administrstion of the Department's research, development and production programme, much of which is carried out by industry. They include the 4,000-strong Aeronautical and Electrical Inspectorates, whose staff are divided between headquarters, regional offices and contractors' works. Although aircraft and guided weapons provide the major part of the work of the 30,000, it covers a somewhat wider field than our inquiry, since it also includes electronics (ground radar and telecommunications as well as avionics) and space research. Furthermore some 4,000 are employed in branches which provide common services for the whole Ministry. Some examples of these are the Establishments (i.e. Personnel), Finance and Contracts Divisions. On the other hand aviation benefits from some of the work of the National Physical Laboratory and the National Engineering Laboratory although they are not primarily engaged on asrospace work and their staff are not included in the above figures. The figure of 30,000 is about 2,000 fewer than the strength of the former Ministry of Aviation at its peak in January 1965. More than half the decrease is due to the transfer of certain civil aviation responsibilities (and staff) of that Department to the British Airports Authority and the Board of Trade in 1966 and 1967 respectively. Thus comparing like with like the present number is about 600 lower than in January 1965.

VALUE OF OUTPUT

16. Table 1 shows the estimated value of the industry's output in terms of sales to final buyers for each year since 1960.

/TABLE 1

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TABLE 1 VALUE OF THE INDUSTRY'S OUTPUT

£ million

Year	Complete Aircraft and Airframe Parts	Engines and Parts	Guided Weapons	Other	TOTAL
1960	188	152	54	19	413
1961	248	157	56	25	486
1962	212	152	62	21	447
1969	218	160	44	25	447
1964	257	156	59	26	498
1985	295	174	65	29	563
1968	299	186	65	29	579
1967	272	216	57	25	570
1968*	321	218	74	32	645
Per Cent of Total 1960-68	49.7	33.8	11.5	5.0	100.0

*Provisional

The figures include research and development, repair and modification work, but in order to avoid double counting they exclude sales by one sector of tbe aircraft industry to another sector. For example tbe value of engines sold direct to alrframe manufacturers for installation in aircraft under construction is included in the final selling price of the "complete aircraft"; it is not counted in the column headed "Engines and Parts". The latter therefore does not sbow the total output of the engine manufacturers, which actually averages some 38 per cent of tbe industry total. The output of the whole industry has increased during the period, although because of the effects of inflation its growth in real terms has been smaller tban the Table suggeats. Figure 1 shows in graphical form the growth in the industry's output since 1948, at current prices and at constant prices baaed on end-1967 price levels.

17. The distribution has cbanged very little: percentages in the bottom line of Table 1 do not vary greatly in individual years. About three-quarters of the output is military (including exports of military aircraft and equipment). Tbe proportion has fluctuated rather irregularly, but from 1958 to 1966 it averaged 76 per cent. Spares, maintenance and reconditioning form a rather large proportion of total production - as mucb as 44 per cent in the period 1963-67. An analysis of the figures by sources of the industry's sales income is shown at Annex C.

18. Total output has risen much less in the second half of the period illustrated than in the first, but this is not also true of productivity. Figure 2 compares output with employment by showing the value of sales to final buyers for each employee in the industry. Like Figure 1 it displays the trend at both current and constant prices. It will be seen that following the rationalisation of the industry which began in 1961, there was a marked rise in productivity.

EXPORTS

19. Table 2 and Figure 9 show the proportion of the industry's total output which was exported. The percentage which its exports formed of all manufactured exports is also shown in Table 2.

/Figs. 1, 2 & 3

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FIG.1.—VALUE OF THE INDUSTRY'S OUTPUT

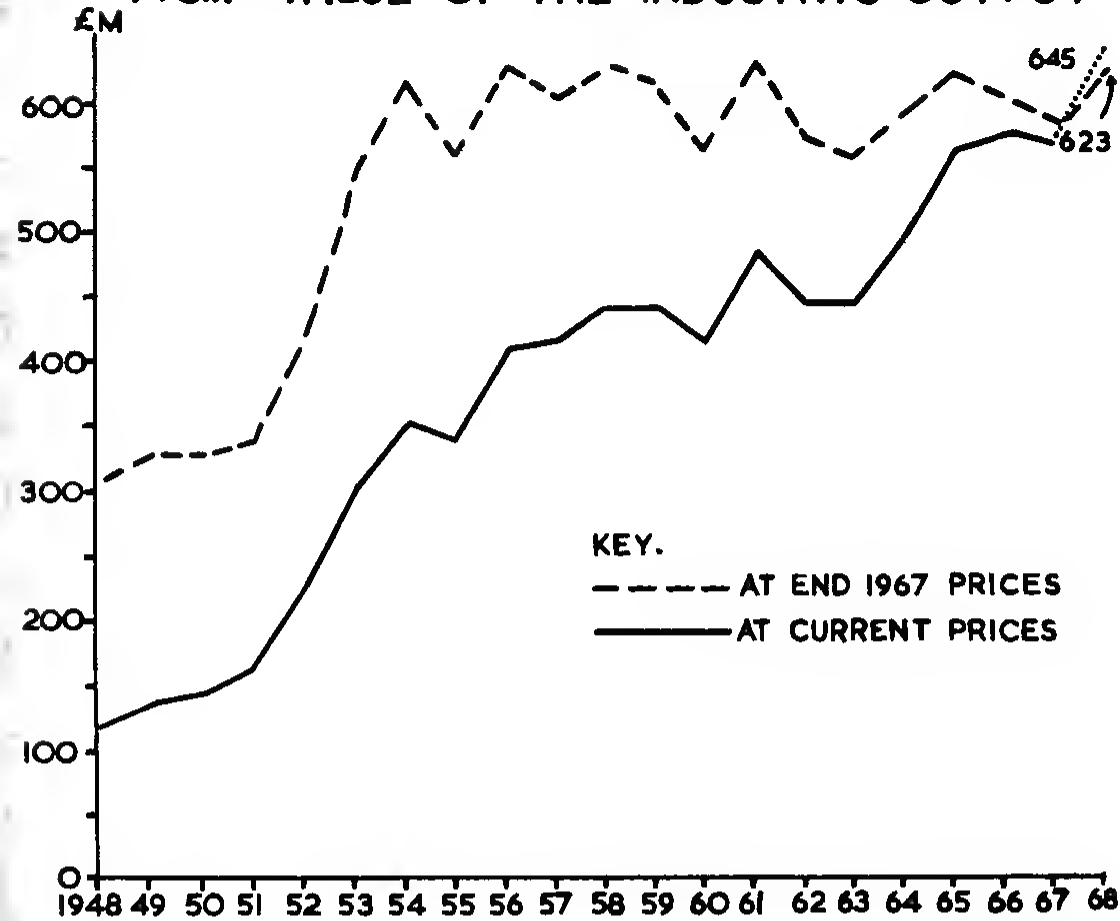

FIG.2.—SALES PER EMPLOYEE

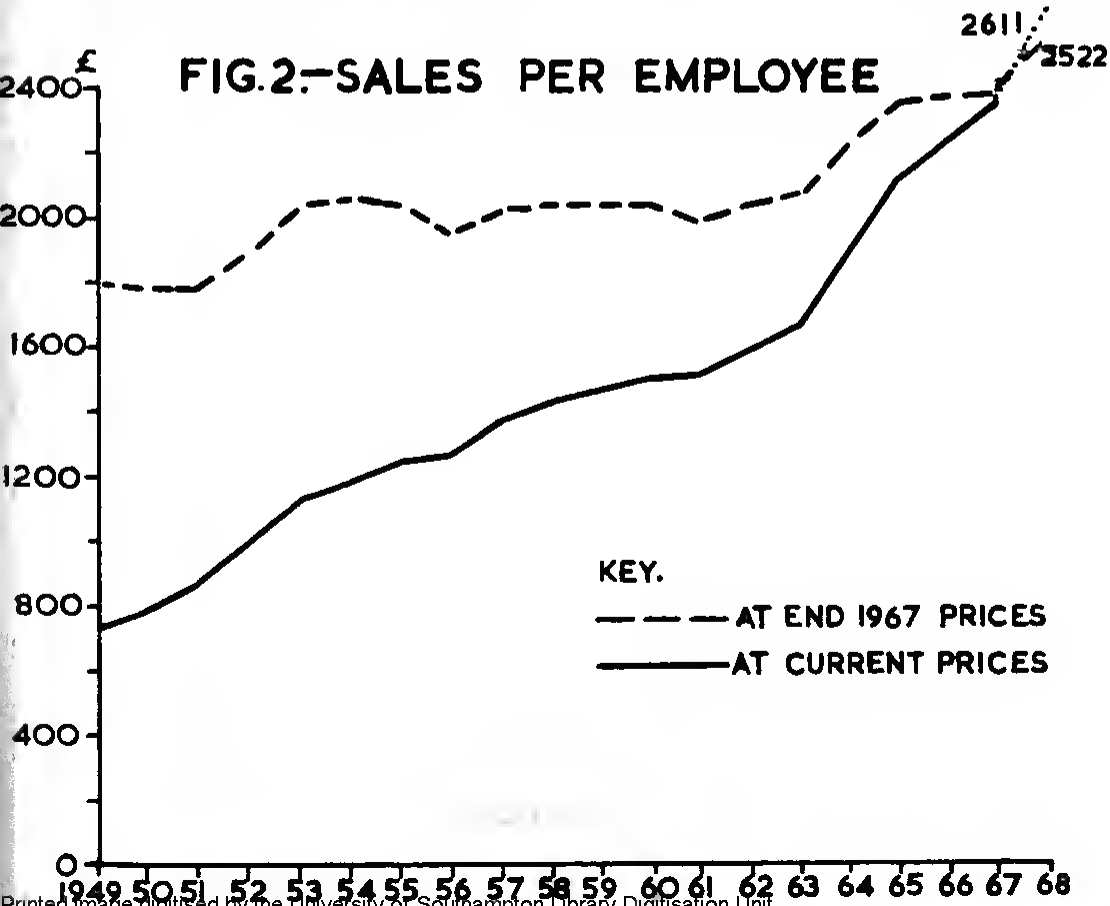

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FIG.3 – AIRCRAFT INDUSTRY'S EXPORT SALES AS A PERCENTAGE OF ITS TOTAL OUTPUT.

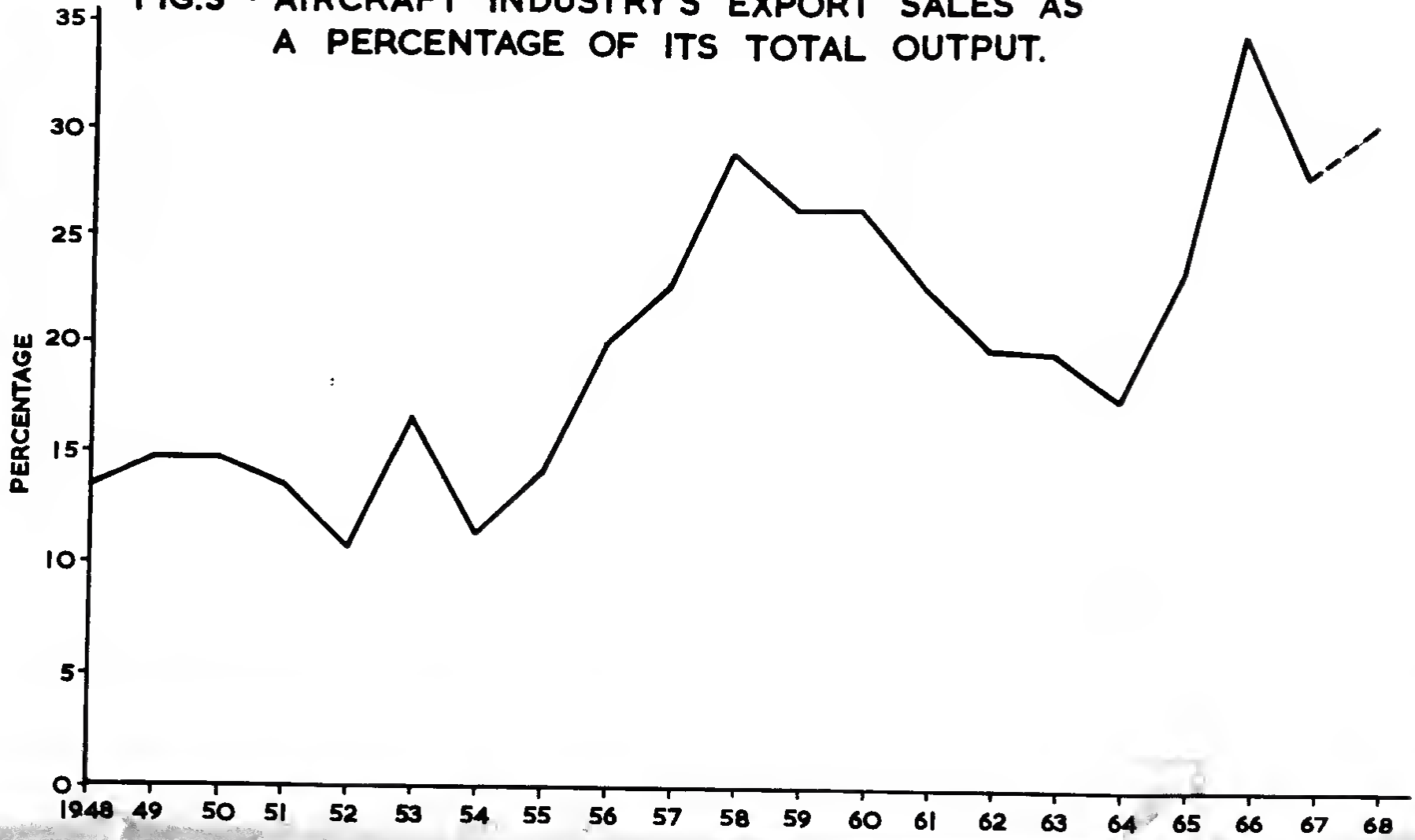

TABLE 2 EXPORTS OF AERONAUTICAL PRODUCTS*

£ million

Year (1)	Total Output of the Aircraft Industry (from Table 1) (2)	Recorded Exports of Aeronautical Products (3)	Export Sales by the Aircraft Industry (4)	Export Sales as Percentage of Aircraft Industry Output (5)	Aeronautical Exports as Percentage of all Manufactured Exports (6)
1960	413	142[a]	109	26.4	4.6
1961	486	151	111	22.8	4.7
1962	447	117	89	19.9	3.6
1963	447	115	88	19.7	3.3
1964	496	102	87	17.5	2.8
1965	563	149	131	23.3	3.7
1966	579	217	199	34.4	5.1
1967	570	201	159	27.9	4.7
1968[b]	645	280	195	30.2	Not available

(a) 1960 figure excludes Guided Weapons

(b) Provisional

Between 1960 and 1967 exports averaged about a quarter of the industry's total output including R & D, and a third of total production, though the proportion fluctuated appreciably from year to year. More than half the exports were civil. Substantial foreign orders for British engines have continued and they are now recovering the ground which they lost between 1961 and 1964. In 1967 sales of engines and spares made up 43 per cent of total exports without counting engines installed in complete aircraft sold to overseas buyers. Exports of guided weapons have remained fairly constant and slightly below the peak 1964 level of £11 million.

/MARKET

*Column (3), compiled by the SBAC, is based on the value of exports recorded by H. M. Customs and Excise and published in the Overseas Trade Accounts. The figures in column (4) are estimates derived by the Ministry of Technology from the Overseas Trade Accounts and from quarterly returns made to the Ministry by major firms in the aircraft industry. There are several reasons for the differences between these two columns in the Table. Column (3) includes some equipment intended for aeronautical use, the producers of which do not fall within the Government definition of the aircraft industry (Standard Industrial Classification, Minimum List Heading 383). Airborne avionic equipment, instruments and tyres are a few examples of such products. They are not included in Column (4) when they are exported independently, either as spare parts or to a foreign aircraft manufacturer. They are counted in Column (4) only when they are shipped installed in a complete aircraft (and therefore cannot be easily segregated). This column also excludes - especially in recent years - the value of products which though temporarily shipped abroad are not being sold to a foreign buyer, but are nevertheless included in the Overseas Trade Accounts figures for exports and subsequently for imports. Examples of these are the Spey engines shipped to the USA for installation in Phantom aircraft produced for the RN and RAF, and parts for collaborative projects in course of development or production with European partners. Column (3) includes the total export prices of used engines which have been returned to the maker for repair and reconditioning. Only the value of the work done on these engines is regarded as current export earnings in Column (4). On the other hand the value of work done to refurbish used aircraft prior to resale abroad, though similarly included in Column (4), is excluded from Column (3).

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MARKET FOR AIRCRAFT

20. Having briefly summarised the resources engaged in aeronautical development and production in Britain, we now consider the principal customers for the industry's products. The Ministry of Technology, acting on behalf of the Ministry of Defence, are the sole domestic purchasers of military aircraft. The domestic civil market is dominated by the Airline Corporations, though less than it was formerly. The Ministry of Defence have recently bought a substantial quantity of aircraft from abroad and civil users continue to purchase a considerable number of foreign aircraft. While domestic orders are important to the industry, they are no longer adequate on their own to sustain it at an economic level. Aircraft have become very complex, and consequently very expensive compared with their predecessors. At the same time they have become faster and more productive, so that fewer are needed to do a given job, whether it is military or civil. For military needs fewer can be afforded, and the rate of growth in the number of civil aircraft required is lower than that of air traffic. At the same time development costs are growing rapidly with the result that the amount of development expense to be recovered in the selling price of each civil aircraft sold is increasing.

21. Fifty per cent by value of the demand for airliners and spares for them in non-Communist countries during the next decade is expected to come from North America. If the markets for small civil aeroplanes and the larger "executive" aircraft are included, the North American share increases to nearly sixty per cent. The remainder is divided about equally between Europe and the rest of the world. Foreign military requirements are much harder to predict, partly because of the security which surrounds them, but chiefly because the world military situation is much less stable in the long term. At present the Forces of the United States operate nearly half the military aeroplanes in the world; over 80 per cent if Communist countries are excluded*. An end to the Vietnam war might lead to a reduction in demand, but the United States are clearly likely to remain the principal buyer of military aircraft in the foreseeable future.

22. It is not surprising that the British industry's main competitors can also be found in North America, where they command a home market which, if by no means captive, offers exceptionally good opportunities to domestic suppliers. Some of the advantages arise from discrimination in favour of American products, like the Buy American Act which applies to all procurement by the Federal Government; except where exemption is specifically allowed. This Act ensures that a very strong preference is given to American and Canadian suppliers. As applied to equipment purchased by the Department of Defense (including military aircraft) in recent years it has accorded a preference to products with at least 50 per cent American or Canadian content, provided that their price was not more than 50 per cent higher than that of a foreign alternative excluding duties. The Department of Defense have recently been criticised for applying this test instead of the alternative criterion used by other Departments, viz. that the domestic price shall not be more than 6 per cent (in certain cases 12 per cent) higher than that of the foreign article including duties. Although, depending on the extent of the duties levied, the adoption of this alternative formula might be rather more favourable to foreign sellers, the difficulties of winning an American order for a complete military aircraft would still remain formidable. The Act is applied somewhat less stringently to foreign components in a product which is itself classified as domestic because it contains at least 50 per cent American (or Canadian) content. Thus equipment and even engines can compete on much more level terms than a complete aircraft.

23. The Buy American Act does not bind commercial airlines, but they too quite naturally show some preference for the products of their fellow countrymen whose factories are close at hand, often on airports where the airline operates. "Brand loyalty" plays a part: it makes good sense economically for an airline to buy from a manufacturer with whom it has had satisfactory dealings before, particularly if the servicing procedure and many of the parts of the latest model are the same as for his earlier types. Orders from one or two major American airlines are normally large enough to justify a project as a reasonable commercial risk. They provide a firm base from which the manufacturer can offer the aircraft to other prospective buyers.

24. Discrimination in favour of domestic producers limits the extent to which free competition prevails in world markets, but it has by no means eliminated it. In the recent competition between Lockheed and Douglas for orders for an "airbus" the American airlines which chose the Lockheed proposal specified British engines in preference to American alternatives. This contest also

/demonstrated

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*Source: "World Market for Aerospace Products, 1965-75"
Canadian Department of Industry, June 1966

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demonstrated the fierce rivalry between American aircraft manufacturers which their larger domestic market encourages. The scope for such thorough-going competition between British producers has been reduced by their concentration into large groups, their dependence on Government financial support for civil as well as military development, and because a number of companies are the sole British specialists in their field. Britain can no longer afford and should not again contemplate, the parallel development of three aircraft to meet a single requirement, as she did in the case of the V-bombers, but domestic competition is not entirely absent. For BEA's recent re-equipment programme there was competition between BAC and Hawker Siddeley and from the American industry too. British companies are exposed to international rivalry, which is often strong, in much of their business. The fact that they do not receive the stimulus of such vigorous domestic competition has not prevented British companies from achieving considerable success in export markets.

MEETING THE CHALLENGE

25. From the preceding paragraphs it should be clear that Britain's aircraft industry in recent years has been subjected to the twin pressures of contracting orders at home and increasingly fierce competition in other markets. Some of the ways in which the industry is meeting this challenge we describe in Chapter 12, and we note with approval elsewhere in our report the efforts the Ministry of Technology have made to strengthen the authority of the project management staff and to collaborate more closely with the industry in forecasting the future demand for its military and civil projects. We hope that the existence of our Committee and the questions we have asked may have given some added impetus and encouragement to the industry's and Government's search for better ways of doing things.

26. Success in this industry depends not only on technical efficiency but also on the skill with which demand is anticipated and the project marketed. British firms are alive to these requirements. A description of their efforts by market research to anticipate future demands and of their selling organisation and methods in foreign markets is given in Chapter 14.

/SECTION II

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CHAPTER 4 THE MEASUREMENT OF PRODUCTIVITY

27. Comparisons of productivity are usually expressed in terms of physical output per man-hour or man-year. Where the products of a particular industry in two or more countries are similar, the number of units produced per man-year can be compared relatively easily. This is not possible between the aircraft industries of different countries because their products differ appreciably. It is therefore necessary for global comparisons to be made in terms of added value per man-year.

28. The added value is obtained by deducting from the total value of goods made and other work done by the industry during the year, the cost of purchases (adjusted for change in the level of stocks), payments for work sub-contracted to other firms and payments for transport. As a measure of the output of the industry it avoids double counting of articles bought by one member of the industry from another member. It also avoids attributing to the aircraft industry that part of the value of its products which is actually the output of a different industry. Raw materials, electronic equipment and tyres are three examples.

29. Added value is reliable as a yard-stick of manufacturing efficiency only when selling prices can be shown to be competitive on both sides, and levels of profit and a number of other factors are comparable. However both the competitiveness of prices and the actual comparisons of value added per man-year depend on the exchange rate chosen for converting one country's figures for comparison with the other country's. Obviously alterations in exchange rates (such as the devaluation of sterling in November 1967) will affect the comparisons. A further difficulty is to to ensure that like is compared with like. A British company is classified to a particular industry if 51 per cent or more of its work falls under the definition of that industry. These definitions do not correspond exactly in all countries. Thus in the United States missiles are classified as a separate group, whereas in Britain they are included under aircraft.

30. In spite of these difficulties, it is possible to make an approximate global comparison for the American and British industries. It gives a ratio of productivity (output per man-year) of 3 to 1. This figure is consistent with the fact that comparable British and American aircraft sell in world markets at about the same price, although workers in the American industry are paid approximately three times as much as their British counterparts. This "productivity gap" is not confined to the aircraft industry; it is found between the manufacturing industries of the two countries generally. It was on this kind of evidence that the Plowden Committee formed its conclusions about the efficiency of the British industry (see Chapter 33 of its Report).

31. This type of comparison shows that a disparity exists large enough to wipe out the advantage which Britain derives from her lower wages and salaries. But it does not tell us what causes the disparity.

32. To obtain some clearer idea of the causes of this disparity in value of output per man, we made other statistical and qualitative investigations. Our aims were first to determine whether there are serious differences between the effort required here and in America to accomplish the same or a generally similar job, secondly to show the effect of production quantity on the effort needed and thirdly to identify any major differences in method and in the way resources are employed.

33. Statistical information in a suitably comparable form for such studies is not always readily available, or indeed available at all. Hence we have had to seize such opportunities as occurred, and to accept their limitations. We believe, however, that taken together they provide a consistent and reliable picture of the reasons underlying the "productivity gap".

34. The most extensive of these studies was carried out for us by consultants, who were able to use as the basis for their comparative analysis the result of some research undertaken a few years ago in the United States by the Rand Corporation. This defined the correlation which has been found to exist between the weight and speed of an aircraft and the direct man-hours required for various tasks in its development and production. It thus provided a yardstick against which we could measure our own achievement. The application to British projects of the equations derived from this investigation, and the conclusions which emerged from it are discussed at greater length in Chapter 6 and Annex D.

/35.

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35. We also had some opportunities of comparing American and British manufacture of identical aircraft or parts of them. They occurred where British companies are producing American designs under licence, or as sub-contractors to the American manufacturers of the Phantom and C-130 aircraft which are being bought for the Royal Navy and the Royal Air Force. These comparisons are discussed in Chapter 7. The following Chapter draws on similar studies made by Rolls-Royce with the co-operation of some American engine manufacturers.

36. Thirdly we were privileged to have access to the conclusions of a further study undertaken in the United States, in which the project histories of a pair of broadly similar British and American civil aircraft - the Vickers VC 10 and Boeing 707 - were compared. This investigation, carried out with full co-operation from the manufacturers, was similar to that undertaken by our consultants, though the concentration on only two projects enabled it to be much deeper. Considerations of commercial security prevent us from quoting the results in detail, but some of them are mentioned in Chapter 6, and we have taken them into account in reaching our conclusions.

37. Finally we supplemented these quantitative studies by qualitative impressions gained during our visits to the United States and Sweden. They are discussed in Chapters 9 and 10 and elsewhere in the report.

/CHAPTER 5

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CHAPTER 5 THE VALUE OF OUTPUT PER MAN

38. In the last Chapter it was stated that a frequently used measure of productivity is the value added to the product per unit of effort. The unit may be a man-hour or man-year. The main sources of information for use in comparisons of this kind are the Censuses of Production, which under this or similar names are compiled and published every four or five years by some industrial countries. The latest year for which such censuses have been taken and published by Britain, the United States and France (the major western aircraft producers) is 1963. The next year for which a full census is being taken is 1968. Sample censuses are taken in intermediate years so that certain trends may be studied but they do not contain suitable information for our purpose. While the British and American censuses contain statistics of value-added for the aircraft industry, the French census defines output in physical terms, so that its results cannot be directly compared with theirs. We have been unable to obtain statistical information from France which would have enabled us to compare her productivity with that of this country in the same way as in this Chapter we compare the United Kingdom with the United States. In depending on information for a single year, 1963, we were conscious firstly that it was rather remote in time for our purpose, and secondly that given the long cycle of aircraft projects a sample of one year might be unrepresentative. This might occur if one country's industry was at peak production on a number of projects while the other's was in a trough with old work running down and new work beginning. The figures must be read with thess reservations in mind.

39. Figure 4 shows some typical proportions of various elements of cost in an aircraft project. It will be seen that value added by the airframe manufacturer is only about half the total, and that of the costs over which he has control, overheads are by far the most important.

40. Average wages and salaries for all employees, and for operatives only are shown in Table 3.

TABLE 3 PAYROLL COSTS - 1963

	UK £	USA £(£1 = $2.80)	Ratio US:UK
AVERAGE ANNUAL PAYROLL COST			
All employees	855	2,780	3.2:1
Operatives only	802	2,335	2.9:1
AVERAGE HOURLY PAYROLL COST			
Operatives only	0.356	1.108	3.1:1

There is a small difference between the ratios of operative annual and hourly cost because British working hours were about ten per cent higher. The value added by, and employment in the aircraft industries of these two countries during 1963 are shown in Table 4.

TABLE 4 VALUE ADDED AND EMPLOYMENT - 1963

	UK	(£1 = $2.80) USA
Value added	£321 million	£3,524 million
Employment	250,600	829,800
Output per man year	£1,281	£4,247

The value added must not be confused with the much higher figure for "sales to final buyers" mentioned in Chapter 3 paragraph 16. The latter, although it excludes double counting of items purchased from other members of the aircraft industry, includes materials and parts supplied by other industries, which as explained in paragraph 28 are deducted in calculating value added. It will be seen that value added per man-year in the United States was some 3.3 times that achieved in the United Kingdom. This ratio was approximately the same as existed between payroll costs in

/Figure 4

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the two countries. The aircraft industry's net output and work force (see paragraph 12) accounted for approximately 3 per cent of the value added by and employment in all manufacturing industry in the United Kingdom.

41. These comparisons at once raise the question of how it is possible for the American worker to produce three times as much as his British counterpart. Does he work three times as hard? Or is his greater productivity to be explained by the extent to which he is assisted by capital equipment? Or are there other reasons?

42. There are no statistics which would have enabled us to compare the total value of capital assets owned by the whole aircraft industry in each country with the size of its workforce. We did so for a few of the largest companies, however, and concluded that the value of fixed capital per employee in the American firms was roughly three times as great as in their British counterparts. This suggests an easy explanation of the similar ratio of value added per employee in the two countries. However during our visits to American companies we did not see much to support this explanation. The manufacturing methods we saw there (we say more about them in Chapter 10) were not very different from those used in this country - certainly not different enough to make the capital/employee ratio by itself a credible explanation of the disparity in added value per employee.

43. Since neither of the two obvious inferences from the comparison of value added per man in the United States and the United Kingdom seemed to us reasonable from what we knew of their respective industries, we pursued other lines of investigation in order to attempt to identify the reasons for the difference in productivity.

44. The disparity in value added per man which has been noted must be seen in perspective. It is not unique to the aircraft industry, but has been found to characterise manufacturing industry in general in the two countries. The productivity of the aircraft industry compares no less favourably than that of other British industries with value added per man in American industry. This provides little comfort however when so much of the demand for British aerospace products must come from overseas.

45. For the reasons given earlier in this Chapter we have been unable to make similar comparisons with value added by the French aircraft industry. No reliable conclusions can be drawn by merely comparing sales figures. Some of our members, through their involvement in Anglo-French collaborative projects, have first hand knowledge of the French industry. Several of the witnesses from the industry and the Ministry of Technology who gave evidence to us have acquired similar experience. It was their firm and consistent impression that productivity in the French aircraft industry was certainly not superior to that of British firms. In the absence of any convincing evidence to the contrary we have accepted this view.

/CHAPTER 6

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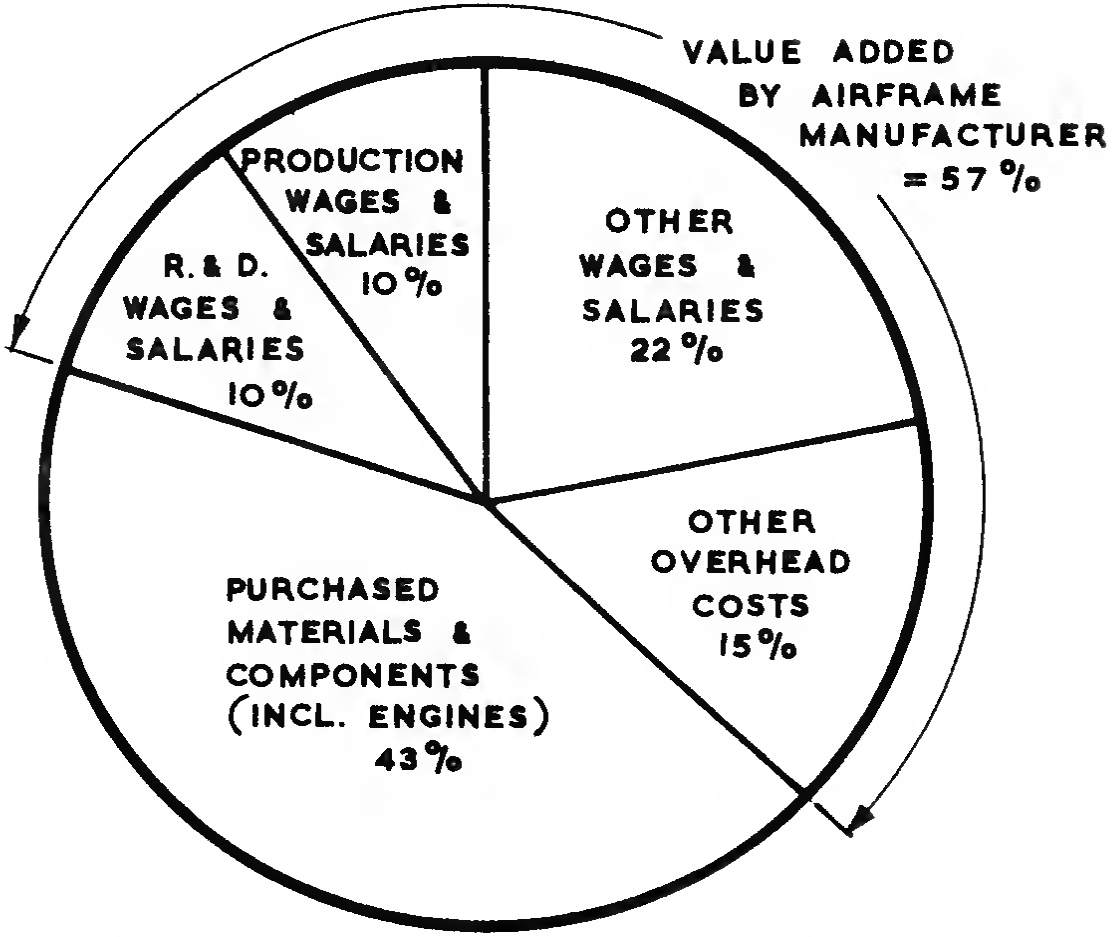

FIG. 4 — ELEMENTS OF COST OF A TYPICAL PRODUCT

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46. The first step in identifying the cause of the 3:1 productivity ratio was to compare the actual man-hours required for the same or similar tasks. Ideally we might have matched a number of British aircraft with American types which resembled them as closely as possible, so that we could compare, for each pair of aircraft, the man-hours expended on design, development, and production in the respective countries.

47. A study of this type on a pair of airliners - the Vickers VC 10 and Boeing 707 - has been carried out, with the collaboration of the manufacturers concerned, by a research team of the Rand Corporation, who were kind enough to discuss their findings with us. To have repeated such analyses for a significant number of aircraft pairs would have required a good deal of time, a large research staff and much goodwill and effort from both British and American companies. We doubt however that they would have been justified because the problems of defining convincingly "similar" pairs of aircraft and of ensuring that information on them was in a strictly comparable form would have been formidable and probably insuperable. The Rand Corporation emphasised to us that their comparison of the VC 10 and Boeing 707 was subject to some qualification because the aircraft were produced at different times and differed in design.

48. Thanks to the other research undertaken by the Rand Corporation, to which we referred in paragraph 34, we were able to adopt a less elaborate approach. Their analysis of twenty-nine American military aircraft projects revealed a fairly good correlation between the maximum weight and cruising speed of an aircraft and the man-hours devoted to design, development and manufacture of the airframe. The sample they studied comprised various American bombers, fighters, strike, transport and training aircraft developed and produced between 1945 and 1963. The research team also studied a group of engines, though in less detail than the airframes, and found that the thrust or shaft-horsepower of a turbine engine and its cost were similarly related. They expressed these relationships in a series of equations, the primary aim of which was to predict the effort and cost of various tasks (such as design, tooling, flight test and manufacture) in the development and production of an aircraft of given maximum weight and cruising speed. Thus they contained in a generalised form the sort of information which would have been needed for each American aircraft in our ideal study.

49. It was a fairly straightforward task to survey a sample of British aircraft, to see whether they exhibited the same correlation. In other words were the actual man-hours expended for the various tasks in this country the same as predicted by the equations? If they were not, the extent of the difference would give us a broad measure of the difference in "real" output per man-hour (as distinct from its cost) here and in the United States.

50. This survey was undertaken for us by Associated Industrial Consultants Ltd. Their report is reproduced at Annex D. In this Chapter we limit ourselves to outlining its scope and commenting on its conclusions. Seventeen British airframes and seventeen engines were studied - smaller numbers than in the American samples. About half the British airframes were civil, whereas the American work was confined to military types. Some of the British engines had both civil and military applications. For each airframe data were collected as far as possible under the headings defined in the American study. Different methods of keeping records made it difficult and sometimes impossible to extract information in the same form as had been adopted by the Rand Corporation. Making sure that they compared like with like was probably the biggest problem the consultants encountered. They found it impossible to obtain data in a strictly comparable form on all seventeen types for each task studied, so that like the Rand team they had to form their conclusions about each stage of a project from information on only a fraction of the total number.

ADJUSTMENT FOR DIFFERENT QUANTITIES

51. Before summarising the conclusions which emerged from our consultants' analysis, we must say something about the "learning effect" because of its important consequences for the comparison of manufacturing man-hours.

52. The phenomenon of "learning" in manufacturing processes first attracted serious attention during the second World War. Since then it has become an increasingly familiar concept, particularly in the aircraft industry.

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53. In this type of work as operatives become familiar through repetition with the peculiarities of a new job, the time they take to accomplish it decreases progressively and at a regular rate. Progressive improvements in method also contribute to the reduction. It has been found that when the man-hours for each example made are plotted against quantity, they form a smooth curve commonly referred to as the "learning curve". It shows that for each percentage increment in the quantity produced, there is a corresponding percentage reduction in man-hours per unit. For example every time the quantity produced is doubled, the man-hours for the last unit decrease by a constant percentage, reflected in the slope of the learning curve. For an "80 per cent curve", a percentage which is fairly typical for airframe construction, if the first unit requires 1,000 man-hours, the time required by successive units will be as shown in Table 5.

TABLE 5 MAN-HOURS ON AN 80% LEARNING CURVE

No. of unit	Man-hours per unit	Cumulative average man-hours per unit
1	1,000	1,000
2	800	900
3	702	834
4	640	785
5	596	748
10	477	631
20	381	524
30	335	467
40	305	430
50	284	402
100	227	327
200	182	264
300	159	232
400	145	212
500	135	198
1,000	108	159

As man-hours for each successive unit decrease, so of course do the average hours for all units made, as column 3 of Table 5 shows. The decrease in the unit and cumulative average man-hours is most marked early in production. As more are made the improvement from one unit to the next becomes smaller and smaller although it can continue indefinitely. This is shown very clearly when the learning curve is plotted as in Figure 5. Consequently when we compare "manufacturing hours" it makes a great difference whether we are referring to the average hours required for a quantity of 10 aircraft, for 100 or 1,000. If the average man-hours for an aircraft made in several hundreds are compared with those for one of which only a few dozen were produced, as has sometimes been done, some very misleading conclusions can emerge.

54. This problem faced the Rand research team as well as our own consultants: the American aircraft in their samples were made in quantities ranging from 50 to more than 3,000. They overcame the problem by standardising on man-hours for the 100th aircraft. The British types our consultants analysed were generally made in smaller numbers, but also spanned a wide range, the smallest production run being 28 aircraft, the largest 540. Where fewer than 100 aircraft were produced the hours for the 100th unit were derived by extrapolation from data on the actual quantity made. In addition the American team produced an equation giving man-hours for any particular unit; in our study it was used for comparison with actual man-hours for the last unit made.

55. We have discussed the learning effect at some length because it is fundamental to the economics of aircraft manufacture, and to the principal conclusions of the consultants' study and of this report.

/Figure 5

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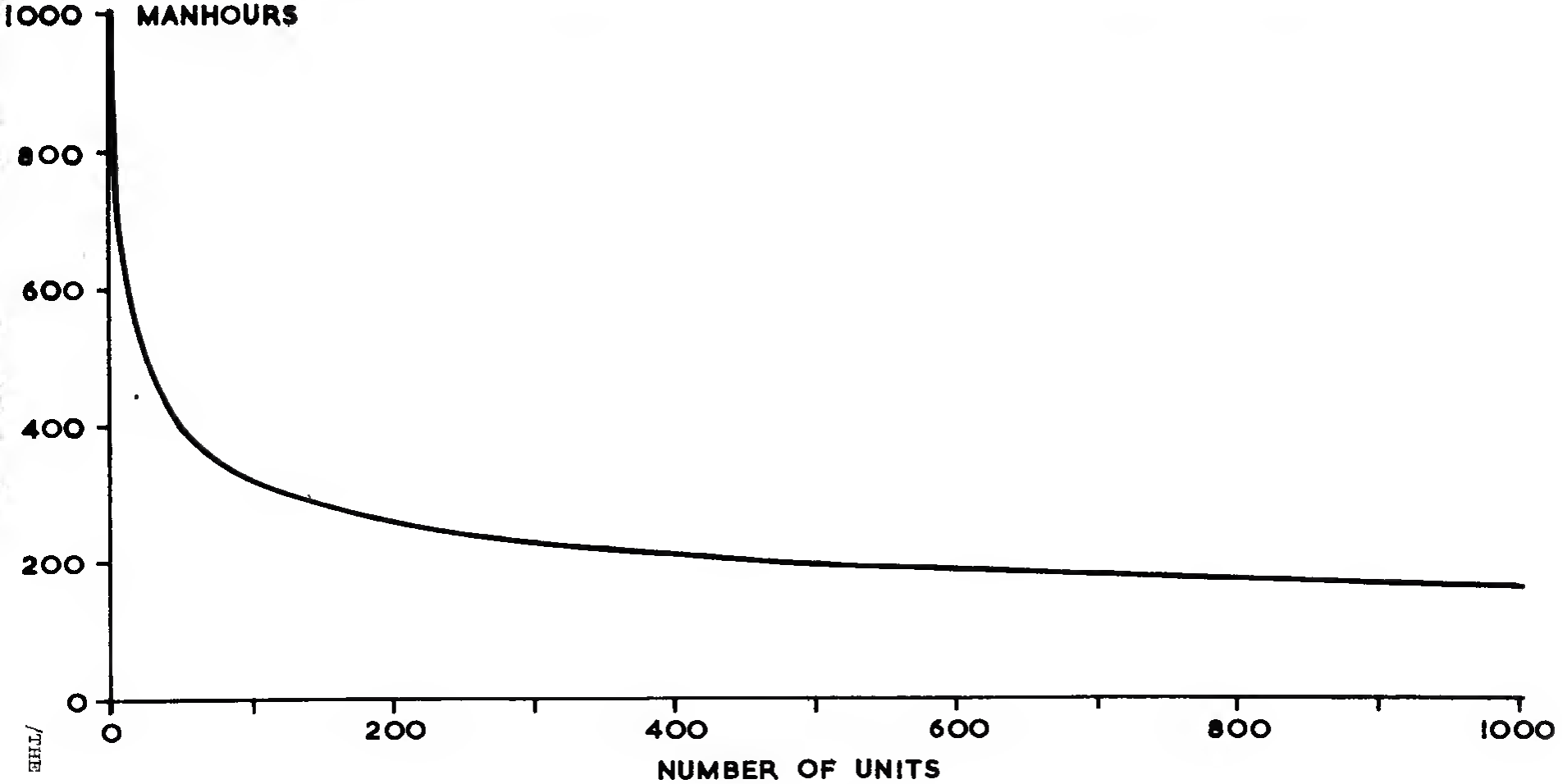
FIG. 5 – CUMULATIVE AVERAGE MANHOURS ON AN 80% LEARNING CURVE



/THE

THE CONSULTANTS' CONCLUSIONS

56. The principal conclusions which our consultants formed from their comparison can be summarised as follows:-

(a) For design, tooling and manufacture of airframes, direct man-hours in the United Kingdom were respectively 14, 43 and 25 per cent greater than predicted by the American formulae.

(b) This disparity coupled with the much larger effect of Britain's shorter production runs, accounts for the global ratio of value added per man of 3:1 in favour of the United States.

(c) For aircraft turbine engines the man-hours required were broadly in line with predictions from the American equations, indicating that productivity in this field is equal.

These Conclusions are subject to a number of qualifications which are set out in Annex D. However we are satisfied that they do not invalidate the conclusions. The comparison made by the Rand Corporation in greater depth, of the Vickers VC 10 and Boeing 707 showed that weight for weight, design man-hours for the VC 10 were 9 per cent less, tooling hours 41 per cent less and manufacturing hours 41 per cent greater than for the 707. These three activities are considered in greater detail in the paragraphs which follow.

DESIGN

57. The consultants found that design staff man-hours for airframes were 26 per cent greater than predicted by the American formula. Where the sample was adjusted to exclude data which were incomplete, or which did not conform strictly to the American definition, the difference became only 14 per cent. We consider that such a small difference can be ignored for two reasons. The first is the unavoidable margin of error in the data used. The second is that work associated with major modifications, excluded in the American study, had to be included for the British projects because it could not be satisfactorily segregated. Although the consultants were unable to identify it in the data supplied to them, one manufacturer has asserted to us that in one of the military projects they studied, as much as 50 per cent of design man-hours were attributable to such changes. This may be exceptionally high but the comparison of the VC 10 and 707, in which the effect of major modifications was excluded where possible, showed that design man-hours for the British aircraft were 9 per cent lower than for the American. It therefore lends some independent support to our conclusion that in the design stage Britain is at least the equal of the United States.

TOOLING

58. The largest disparity noted by our consultants was in man-hours expended on design and manufacture of tooling. Averaging 67 per cent more than the predicted figure for all the British projects in this sample, it was still 43 per cent higher in the adjusted sample. Furthermore the definition of this activity used by the American researchers included production control. In Britain this had to be excluded because it proved inseparable from other indirect tasks. If it could have been included, the 43 per cent more effort which the United Kingdom devoted to tooling would have increased to some 60 or 65 per cent.

59. We found this disparity surprising, particularly since it was not confirmed by the study of the two civil airliners, which revealed an almost equal difference in favour of the British project. There is some reason for thinking that Boeing equipped themselves for a large production run while the British manufacturers matched their tooling to the much smaller sales they had in prospect. The consultants' figure is open to some doubt for reasons which they have clearly pointed out. Nevertheless the implications of small scale production would lead to the expectation that effort devoted to tooling in the United Kingdom would be relatively less effective. Where volume of output is low, specialised tooling may spend much time idle: one set may be sufficient to handle several times as much work without demanding any greater effort for its design and manufacture. Durability likewise cannot be scaled down in proportion to production: the tooling for fifty aircraft may necessarily be made to a quality which would suffice for five hundred.

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60. The solution to this problem, as to so many others, depends very largely on improving utilisation by increasing the scale of production. But although we believe that the steps we recommend later in this report will help the industry to market its products in greater numbers, it may not always be possible to do so to an extent which overcomes these problems. Because of this, a very cost-conscious approach to tooling is needed. We have more to say about Production Control in a later Chapter.

MANUFACTURING LABOUR

61. The disparity which the consultants found to exist in manufacturing labour was smaller than for tooling, but still large enough to be significant. It was 38 per cent in the unadjusted, 25 per cent in the adjusted sample. Here the more detailed comparison of two civil airliners supports their conclusion: for the two projects compared, weight-for-weight the British man-hours were 43 per cent higher. A British disadvantage in manufacturing man-hours, even a small one, is more serious than in "non-recurring" activities such as design and tooling. The larger the quantity over which the cost of non-recurring tasks is amortised, the smaller will be their contribution to the cost of each unit produced. But if British manufacturing hours exceed those of competitors, the British product will cost proportionately more than it need and this proportion will not be reduced merely by making more units.

62. We believe that there are two separate reasons for the difference in manufacturing man-hours. The first, and in our view the more important, is the effectiveness with which labour is used. The second lies in how hard people actually work. The first is determined chiefly by the efficiency of production control, while the second depends largely on the methods used to stimulate output, whether by incentive bonus payments or by supervision. We say more on both these subjects in detail in later Chapters of this report.

THE LESSONS OF THE STUDY

63. Although the results of the consultants' study must be qualified, its two main lessons are quite clear. The first is that it is the scale of production more than any other single factor which accounts for the 3:1 difference between the United States and this country in the value added by the aircraft industry for each man it employs. If this ratio is corrected for the effects of learning and for the difference in production quantity in the two countries it is reduced to something like 1.5:1. This is a little higher than any of the ratios derived by our consultants from the project data they analysed. They all contain a margin of error and we conclude that the true ratio of the "effectiveness" of manpower in the two countries lies somewhere between 1.2 and 1.5:1. For our purpose it was unnecessary to establish its value more precisely: the study demonstrates clearly enough that the 3:1 ratio of value added per man depends on quantity much more than on the true physical output of each employee. But it also shows that there is a real disparity to Britain's disadvantage in the direct man-hours devoted to certain activities in the two countries. One of these is tooling for airframes, another their actual manufacture. Production on a larger scale would help to counteract the tooling disparity, because it would enable tools to be used more effectively, more intensively and for a greater proportion of their potential life. It would not necessarily have the same beneficial effect on the British disadvantage in manufacturing hours unless producers exploited to the full the opportunities which larger quantities offer of using labour-saving techniques, efficient division of work, and value engineering to an extent which is not usually possible or economic for short production runs. When these means of economy cannot be employed to the full the result is often a lower rate of learning. A levelling-off of learning effect is often observed as a production run nears its end, particularly when workers cannot see further work in prospect to give them continued employment. The effect of this levelling on cost will clearly be greater for short than for long runs. Except in regard to tooling, the independent study of two civil airliner projects confirms the two lessons of our study. It is towards the twin goals of increasing production quantities to more economic levels, and manufacturing them more efficiently, that we direct most of our recommendations.

/CHAPTER 7

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64. It is usually possible to compare productivity only on similar jobs: rarely is identical work carried out in two different countries except when a company licenses another to produce its designs. Even then the licensee may modify the basic design for his own market so that the product is no longer identical with the original. Most of the complete aircraft which have been produced under such arrangements in Britain and America in recent years, namely helicopters, have been altered in this way. The modifications vary in extent but they do not usually change the helicopter fundamentally. We obtained some comparative information on the cost of some of these helicopters but could not compare actual manhour figures.

65. The American Bell Helicopter Company licensed the production of its model 47 series in 1952 to the Agusta Company of Italy who have since made about 1,000 of this type as well as producing several other Bell designs. When the British Army decided to purchase one Mark of the Model 47, known as the Sioux, the first 50 were manufactured by Agusta. Succeeding aircraft were made under further licence in this country by Westland Aircraft, who continued however to buy a substantial number of components from Agusta. These included the transmission, a costly item which, with the rotor head, can account for a third of the total cost of a helicopter.

66. The British and Italian manufactured aircraft differed hardly at all in price and were about 17 per cent lower than the estimated price of aircraft to the same standard if produced in the United States. Since Agusta were well down the learning curve when Westland began their production, and many hundred aircraft had been produced in America, the British productivity seems to match and possibly exceed that of the other sources.

67. The Sea King helicopter, which Westland are producing for the Royal Navy from a Sikorsky design, the SH3D, will be modified to carry different equipment and to use the Bristol-Siddeley Gnoms engine. This is a British version, also produced under licence, of the General Electric T-56 engine. The Westland estimate for production of the airframe was not significantly higher than that made by Sikorsky, who had the benefit of substantial production experience of the type.

66. Both the engines in various versions power a number of helicopters. The Small Engine Division of Rolls-Royce - where the Gnome is now produced, following the merger of Bristol-Siddeley and Rolls-Royce - had no comparative manufacturing data on its American counterpart. They were however able to quote us prices from both sources for a sample of over thirty parts which are virtually identical in both engines. At an exchange rate of $2.40 = £1, the British parts are on average nearly 15 per cent cheaper than the American. The difference varies greatly for individual parts. In some cases the American component is twice as expensive as the British, while in others it is a good deal cheaper. The Gnome engine has been produced in very much smaller quantities than its American equivalent, but despite this many of its main components can be manufactured competitively, and sometimes very much more cheaply here than in the United States.

MANUFACTURE OF MAJOR SUB-ASSEMBLIES

69. When the Government decided to purchase Phantom and C-130 aircraft from the United States for the British Services, they stipulated that British firms should be invited to tender for the supply of some of the major sub-assemblies and components which the airframe manufacturer normally obtained from sub-contractors. Quite a number of these bids were successful. They offered an opportunity of comparing the manufacture of identical units of considerable size, such as wing sections, the fin, rudder, aft fuselage and tail cone of the Phantom and a substantial fuselage panel of the C-130, as well as many small items of equipment.

70. The British tenderers, although not subject to the Buy American Act in these instances, were nevertheless at a disadvantage since they had to quote for production of items which to them were quite new, in competition with American firms who had the benefit of long experience of the work. The successful tenders were in no case more than about 20 per cent higher than the corresponding American bids; this was the premium the Government were prepared to pay to reduce the foreign exchange content of the aircraft they were buying. In several cases the British prices were somewhat lower than those quoted by the established American suppliers.

71. The quotations we have seen were fixed prices, and the manufacturers were not always able or willing to supply us with details of the manhours required for their own work or that of the licensors. Where we were able to compare manhours as well as costs, we found that although

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British costs were competitive and sometimes lower, unit manhours exceeded those of the corresponding American firm by anything from 20 per cent to more than 80 per cent. This was mainly attributable to the small production quantity required for the British order. To give some idea of the scale of difference, an American manufacturer had produced 2,500 oil cooling radiators at a rate of 50 per month. The British producer whose tender was accepted received an order for 110, at a rate of 10 per month. The American firms benefited from prolonged learning while the British companies started from scratch. Furthermore with their quantities and rates the former could justify the use of special machines, or better fixtures and jigs. They could also sub-divide tasks, making each operative's job simpler and more repetitive. The British quantities were too small for this to be feasible. If their price was to be economic British firms had to keep special tooling to a minimum, and place greater reliance on manual skill, with each operative handling several operations. The challenge which this presented stimulated some ingenious methods which enabled the British sub-contractors to equal and sometimes exceed the quality of the American products, though not usually at an appreciably lower cost.

CONCLUSION

72. These comparisons of basically very similar, sometimes identical aircraft and components confirm both the qualitative evidence of the previous Chapter and also the conclusions drawn from it even though for the most part we have had to deal with prices rather than manhours.

/CHAPTER 8

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CHAPTER 8 AERO-ENGINE DEVELOPMENT AND PRODUCTION IN THE UNITED KINGDOM AND THE UNITED STATES

SOME STUDIES BY ROLLS-ROYCE

73. When we described in Chapter 6 our consultants' comparison of airframe and engine projects, we explained that they had been unable to examine the latter as deeply as the former. Consequently there was a greater margin for error in the case of engines than airframes. We were therefore glad of the opportunity of examining the results of some comparisons made by Rolls-Royce a little earlier, but using more recent information.

74. Rolls-Royce compared the design and development costs of a number of their engine projects, both with the costs predicted by the American research which our consultants used, and with known costs of equivalent work in the United States. These comparisons showed that for corresponding tasks and engines of similar size and power, Rolls-Royce's costs were consistently about half the American figure (at an exchange rate of $2.80 = £1).

75. This was a very gratifying conclusion, but in the past, even with this advantage of lower R & D costs, Rolls-Royce were not able to quote prices for civil engines much below those of American engines of similar size and performance. Hence they made comparative studies of some of the elements of engine cost in more detail when opportunities occurred.

76. Wages and salaries constitute the largest part of the cost of an engine, as of an airframe. We saw in Chapter 5 that for the whole American aircraft industry remuneration in 1963 averaged approximately three times the level in this country; this was true also of the average pay of operatives. However an average for all types of employee could conceal quite wide variations in the ratio of pay of other individual grades of worker in the two countries. Taking research and development staff first, Rolls-Royce devised a hypothetical project team of fifty people comprising design, development, stress and clerical personnel at appropriate levels and calculated their salary cost. They then obtained an independent American estimate of the salary cost of a similar group in the United States. The team was estimated to cost £80,000 per annum in Britain; $478,000 or just 2.1 times as much in the United States. Thus in keeping their development costs down to half the American level, Rolls-Royce have been clearly reaping the full benefit of their lower payroll costs.

77. For production labour the company found that in the United States average hourly rates for direct operatives varied between 2.2 and 2.7 times their own - rather lower ratios than quoted in Chapter 5. These figures must, however, be treated with some caution, since the definition of "direct" workers tends to differ considerably in the two countries.

78. The cost of direct labour itself does not account for a very large part of engine production cost, which is influenced at least as much by other elements. These include the advanced and expensive materials modern aero-engines demand as well as the factor by which the direct labour cost is multiplied to allow for overheads.

79. Rolls-Royce also compared the cost of manufacturing in each country four engine parts of their own design and four of American design - including such items as a compressor disc, shafts and nozzle vane assembly. The results showed a very wide spread. The British estimated costs ranged between 35 per cent and 88 per cent of the American and showed no correlation with the origin of the design in Britain or the United States. The sample was too small to suggest any reasons for this irregular pattern but other studies reported by the company suggest that it was most probably due to wide differences in material prices coupled with variations between the two firms in method, and hence in direct labour manhours.

80. Taking a sample of ten types of material and ten bought-out components used in their engines, Rolls-Royce found that the price of them in the United States ranged from 22 per cent to 254 per cent of the British price. A comparison of Rolls-Royce direct manhours (using a standard definition of direct effort) for ten jobs compared with estimates for the same work in the United States also showed considerable variations. For some of them the American estimate was as much as 23 per cent below the British figure, while for others it was up to 20 per cent more. When totalled, however, they differed by only 3 per cent. A comparison of overhead costs in the two countries gave similar results. The proportion contributed by particular elements of overhead differed considerably in the two countries, but when aggregated they came to a very similar percentage applied to direct labour.

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81. Finally the company made some comparisons of tooling cost. The American approach to tooling differs in several ways from their own. For example the Americans make less of their own tooling and buy more from specialist suppliers. They also expect suppliers of forgings and castings to carry out more of the initial machining operations on them and they allocate tooling costs differently from Rolls-Royce.

82. This made it difficult to form any but the most tentative conclusions, but it appeared that tooling costs in the United States were at least 50 per cent more than in this country, and often considerably higher.

83. Quantity has a somewhat less critical effect on the cost of engines than on the cost of airframes. This is because as has been shown, the effects of learning are very much diluted as quantity increases and engines are produced in much larger numbers than airframes. Two, three, or four engines may be installed in each airframe, and their life (or rather the life of many of their components) is a good deal shorter. Rolls-Royce estimate that for every engine they sell they provide over the years something approaching an equal value of spare parts. Large operators hold a number of additional engines in hand, to avoid grounding their aircraft whenever an engine overhaul or repair is necessary. Moreover, some engine components, like compressor and turbine blades, are used in large numbers in each engine. This is not to say that the length of production run is unimportant to the British engine manufacturer, for he still produces his designs in much smaller numbers than his American counterparts, though he may have to provide just as many variants of the basic model. So while Rolls-Royce enjoy certain advantages over British airframe manufacturers in amortising the non-recurring costs of a project, they face similar disadvantages in competing with American producers. The company believe however that this only partly explains why, although many of their costs were lower than American manufacturers', they have been unable to offer significantly lower prices for directly competing engines. They attribute it also in part to the complexity of some of their earlier designs. A determined attack on this problem by the methods we describe in Chapters 12 and 18 is now showing results, but there is some evidence to suggest that still further improvements can be made.

CONCLUSIONS

84. The studies by Rolls-Royce which we have summarised in this Chapter, like our own investigations, were limited by the availability of information. But they offer some useful confirmation of the conclusions which our consultants drew from their work on engines. The examples analysed tend to show approximate overall parity of actual manhours for equivalent work, both in development and production of engines in Britain and the United States. Within this overall parity a wider variation was found among individual components. Because engines and their components are produced in much larger quantities than the airframes they power, the manufacturing cost of engines is somewhat less sensitive to the effects of production quantity, and British engine manufacturers, although their production volume is small compared with American output, are able to gain some benefit from their lower wages and salaries. With continued efforts to design for production the present competitive advantage can be increased.

/CHAPTER 9

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CHAPTER 9 AIRCRAFT DEVELOPMENT AND PRODUCTION IN SWEDEN

85. In previous Chapters of this report we have described various statistical comparisons of the performance of aircraft industries in Britain and other countries, principally the United States. We now turn to the more subjective impressions which we formed during our visits to Sweden and the United States. The former aroused our interest as a country with substantially smaller resources than the United Kingdom, which yet manages to sustain an apparently healthy aircraft industry. With a population of just under 8 million, a gross national product of about £11,000 million and a national budget less than a quarter of Britain's, Sweden has nevertheless found the means to develop a series of advanced military aeroplanes and to produce them in substantial quantities without seeming to run into the problems of rising cost and wasteful cancellation which have bedevilled the British aircraft industry. During the last twenty years Saab have produced 660 "Tunnan" fighters, 440 of the "Lansen" in strike and fighter forms and are completing the Royal Swedish Air Force's order for the "Draken" which for all roles totals 550. RSAF orders for the Viggen, which made its first flight in February 1967 and is planned to enter service in 1970, already total over 150. We accordingly felt that there might be useful lessons to be learned from the Swedish approach.

86. A group of our members therefore paid a short visit to Sweden, where they had very candid and helpful discussions with members of the Royal Swedish Air Force Board* and of the two companies principally engaged in aeronautical work the airframe manufacturer SAAB and Svenska Flygmotor, the aero-engine specialists. The impressions which they gained, and which form the subject of this Chapter cover a wider interpretation of productivity than simply output per man-year which we have hitherto used. Here we consider the many factors which seem to us to contribute to the successful achievement of an ambitious programme of development and production.

87. Before turning to them in detail we must acknowledge, without wishing to belittle this achievement, that the defence of Sweden is a purely national problem, simpler and more stable than that which confronts the United Kingdom with its many international obligations. On the other hand it presents its own peculiar difficulties to an aircraft designer. The Viggen weapon system, although less advanced than certain combat aircraft of other countries, has been designed to provide the best system the country can afford, and it incorporates novel features which call for a high level of design competence. It is already a reality even though not yet fully proven.

88. The Royal Swedish Air Force Board is not, as might be supposed, concerned with running the Air Force as a whole. Its new name* makes its function clearer. It is responsible for supplying the Air Force with equipment and all three services with missiles, and for maintaining all Air Force equipment. Its roles are akin to those of the Ministry of Technology's Aviation Group and the Engineering Branches of the Ministry of Defence (Air Force Department). It has about 1,600 people on its complement. The management team running a project such as the Viggen (or System 37, as the Swedes prefer to call it, since they regard the actual aircraft as only one part of a weapons and logistic system), is only a fraction of this number. Like the Ministry of Technology, the Royal Swedish Air Force places contracts for most of its research, development and production on commercial firms. However the differences are more illuminating than the similarities. The compactness both of the Government organisation and of the main contractors coupled with the mobility of personnel between them promotes very close co-operation and mutual understanding. We sensed a very close and constructive collaboration between the Air Force (the User), the Air Force Board (the Supplier) and the Contractors. This collaboration is apparently proving effective since the Viggen made its first flight on the planned date, and there has been only a modest increase in the estimated cost of the project.

89. There are a number of factors to which we attribute the Swedes' success in controlling their programmes. Perhaps the most important are the great care which they give to defining the project, and the close association of the main contractor with this process from the first. This stage of the Viggen was supported by some 200 studies undertaken by Saab at a cost to the Swedish Government

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*Since our visit, the Royal Swedish Air Force Board, as a result of a reorganisation, has become the Air Materiel Department of a new Materiel Administration of the Armed Forces. This chapter however describes the Swedish procedure as we encountered it.

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of about £4 million. They inevitably took rather more time than Britain could afford to devote to project definition, and we believe that a smaller number of more comprehensive investigations would be more appropriate to British projects. Nevertheless the principle is very sound and we return to it in Chapter 16. The studies provided those who were determining the specification with realistic technical and financial information on what could be achieved within the funding approved by Parliament for the system in the current Defence Plan. The Swedes do not work out their ideal weapon and then try to estimate what it will cost. They start with a figure which they can afford and then work out what it will buy. We believe that this encourages a more realistic attitude towards the cost of a project.

90. The Swedish specifications try to make the greatest possible use of established techniques, to create a system which can be adapted to new roles and new equipment and be further developed without major re-design. Thus the basic Viggen is designed to be used, with the addition of various weapons and other systems, in four different roles - attack, interceptor, reconnaissance and training. The use of established techniques includes the choice of engine. However the American JT8D engine, which powers a number of current subsonic civil airliners, required considerable adaptation to enable it to propel a supersonic military aircraft. It presented the biggest challenge in Sweden's long history of powering its aircraft with engines designed in other countries and manufactured under licence.

91. The Swedes recognise that timely decisions are essential if firm control over the programme is to be maintained. The timetable for major decisions is agreed and adhered to resolutely by the Contractor, the Air Force Board and the Ministry of Defence.

92. The monopoly enjoyed in Sweden by the suppliers of airframes and engines does not appear to engender very close official surveillance of their expenditure on Government contracts. The Air Force Board have in the past employed the cost-plus-profit type of contract for development and initial production work, with fixed prices negotiated for production. They are now experimenting with a target incentive and a fixed price type of contract for late development and initial production where the technical and acceptance test specifications are clearly defined and development is within the state of the art.

93. A private company of accountants is retained as an independent auditor to examine the contractor's cost records when fixed prices have been agreed, and to advise the Air Force Board whether quotations for subsequent work appear "fair and reasonable" in the light of previous cost experience. A profit of 10-15 per cent of actual costs is usually regarded as reasonable. In the examples we were shown of the proposed incentive contracts, a profit of ten per cent was allowed on the target cost. If actual cost was less than the target, profit would increase to a maximum of 15 per cent of target cost (or 17.7 per cent of actual cost). We understand that this would represent a similar return on capital employed. There is not yet enough experience of the incentive type of contract for its effectiveness to be assessed, but both the companies and the Government appeared content that the existence of a central auditor gives both parties a fair deal. It certainly impressed us as saving a great deal of administrative time, effort and cost as compared with British practice.

94. The Swedish Air Force is satisfied that its contractual procedure does not allow its suppliers to charge excessively high prices. The monopoly which the airframe and engine companies enjoy in their own country does not shield them from the competition of foreign military aircraft: the Air Force, at all stages of a project, considers whether alternative aircraft purchased from abroad could meet its requirement more cheaply.

95. When our members visited Sweden they were not able to see production of the Viggen in full swing as it had only just started with a first order for 100 aircraft. However three points which the company emphasised when explaining their methods particularly impressed us, and were later to be confirmed in American factories. The first was the importance of communication: everyone must understand what he is doing and where and how it fits into the whole project. This was particularly stressed in relation to network control of research and development. The second was the care with which production is planned so that operatives are kept fully occupied and the progress of work through the shops is monitored as it takes place. Thirdly, the pay of pieceworkers - and most of the productive employees were paid on some type of incentive basis - was geared to a learning curve, so that they had to improve their productivity progressively in order to maintain their earnings. The system was quite elaborate, as it must be to cope fairly with the various situations which arise for example, when operatives are transferred to another type of work.

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96. We refer to it in more detail in a later Chapter. Our purpose in the present Chapter is simply to describe some of the main features of Sweden's approach which, in our view, enable a country with smaller resources than Britain commands to carry to a successful conclusion the development of worthwhile military aircraft and to manufacture them at a price at which the country can afford to buy them in substantial quantities for its own Forces. How the lessons of the Swedish approach might usefully be applied in Britain we discuss in the appropriate Chapters of Section V of this report.

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CHAPTER 10 THE LESSONS OF A VISIT TO THE UNITED STATES

97. The world aircraft market is dominated by North America, both as producers and operators of aircraft. We felt therefore that we might learn a good deal from visiting the United States and comparing their manufacturing philosophy and methods with those of the United Kingdom. A group of our members accordingly spent some time in the United States, where they visited a cross-section of aircraft manufacturers, an airline with experiencs of British aircraft and the research team who had carried out the productivity comparisons we cited earlier in this report. Our objects were to learn what the Americans thought about British production methods, and to study the way in which they themselves dealt with the special problems of aircraft manufacture.

98. Soms of the people we talked to were reluctant, or did not feel able to express opinions about British methods. Others did so, frankly and constructively. Their criticisms were remarkable for their unanimity, and for being concentrated virtually on a single point. They had a high regard in general for the quality and performance of the products of the British aircraft industry, but little faith in its ability to deliver them on time. Their experience had shown this to be true whethsr the product they were buying was a complete aircraft or a small piece of equipment. They believed that British firms were insufficiently awars of the importance customers attached to timely delivery and therefore did not plan their production with the care and thoroughness which the increasing complexity of modern aircraft demanded. That this was a matter which called for improvement we were aware; we had earlier set up a working party to advise us on the subject. In the United States however it is treated almost as a religion: one of our informants described his company's attitude succinctly with the remark, "The schedule is our god!" We saw abundant evidencs of the truth of this statement in the effort they devoted to ensuring that work flowed smoothly and continuously so that expensive labour was kept fully employed and the competitive disadvantage of its high cost kept to a minimum.

99. It was in fact the most significant difference which we found between the Amsrican and British approach to airframe manufacture. In general, aeroplanes are put together in very much the same way in the United States as they are hers. Despite the very large numbers in which some of the aircraft were being turned out, the manufacturing processes were generally neither more automated nor even more mechanised than in British factories, nor were they always performed by a particularly elegant or refined method. The only exception we encountered was the introduction of automatic rivetting machines to handle certain large panels.

100. The emphasis on production control was equally marked in all the plants we visited whether they were making aircraft at the rate of two a day or two a month. We discuss in a later Chapter the essntials of an effective production control system, in particular the need for prompt feed-back of information. It is easy to assume, given that a modern aircraft may contain tens or even hundreds of thousands of individual parts, that close control of their progress is only possible by using computers and electronic data processing equipment. We were therefore surprised to find that in ons large enterprise which was producing advanced military aircraft in large numbers, the collection and collation of information on the progress of work in the factory was still carried out manually although a computer was used for planning. "Three or four clerks on the night shift" compiled the records of each day's achievement in a very large assembly shop and a summary of the performance against targst of every work station, which was available the following morning to the shop manager, foremen and charge hands. The process will be transferred to a computer in the near future, a change which has engendered some apprehension among those who depend on the existing system. Another manufacturer considered that his output of aircraft, which was at a lower rats comparable with that found in British firms, simply did not justify the use of a computer for this purpose.

101. In addition to establishing target times and carefully monitoring actual performance against them, the firms we visited took great care to ensure that operatives were kept continuously employed and that waiting time was kept to a minimum. For example, in two of the factories many components were kept in racks at the actual work station, so that operatives did not have to go to a central store to draw them. Moreover the stock was immediately and continuously visible to operatives and their supervisors who wsre thus soon aware of any impending shortages.

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102. Thus far we have stressed the importance of production planning and control in ensuring that work is completed on time. As employed in the companies we visitsd it is also vital to the maintenance of "learning" over production runs which may extend to several hundred and sometimes thousands. This was achieved hy quite different means from those employed in Sweden. The operatives in the American factories we visited were all paid at a flat hourly rate which varied only according to their grade or length of experience. None of them received any incentive payment for higher output, and we were given to understand that this was true of the American aircraft industry in general. It was the middle levels of management who were rewarded for high output in the companies where this was done at all.

103. All the firms we visited employed basically similar methods to ensure a steady and sustained reduction in the time taken for each job. They set target manhours for each job as part of the production planning task. From week to week, or some similar interval, these are progressively reduced in accordance with the expected rate of learning. These targets are given to the foremen and chargehands and it is their responsibility to see that the time allowed is not exceeded even though the number of men they are allotted for the job is progressively reduced as time goes by. Their success is closely and frequently monitored, and they are very quickly informed if they are falling behind the target. It was not very clear to us what means, apart from an authoritative personality, the foremen had at thsir disposal to ensure that they did not fall behind. Their only apparent sanction was the power to downgrade anyone who did not pull his weight. Most of the companies had some kind of job evaluation and grade structure so that an employse could suffer financially if his grade was reduced.

104. We are somewhat doubtful that this alone constitutes a sufficient spur to enable the targets to be met so consistently, as was claimed, but we may not be making enough allowance for differences in attitude between American and British workers. These differences probably also account for the success of the schemes to improve quality, which existed in very similar forms in all the companies we visited. Stimulated by the United States Government's "Zero Defects" programme, their aim is to develop a greater concern for quality among production personnel. Although there are works and external inspectors in American factories, the hasic responsibility for quality is placed firmly on the man who makes the article. Detailed records are kept of the incidence of defects in the work of each small group or even individuals, who are thsmselves reminded of them hy charts displayed at their place of work. Sustained work with few or no defects is rewarded by a public presentation by a senior executive, perhaps the company presidsnt himself, of some small token such as a hadge or tie-clip. The presentation as well as the scheme itself is publicised by normal public relations techniques. All the companies were enthusiastic about the improvement in quality this approach had producsd and the response which it had aroused, especially on the shop floor. One feature of which much was made was the satisfaction which recognition gave to employees who had hitherto felt that they were little more than numbers to the people at the top. One or two firms in the British aircraft industry are already experimenting with similar schemes for improving quality. We recommend that the managements of other companies should consider how they can follow this example, for there can be no doubt that the techniques are proving effective and worthwhile in American firms. We are doubtful whether simply transplanted in their American form they would he so successsful in Britain. They would need adaptation and skilful presentation to arouse the same degree of enthusiasm among British employees and avoid conflicting with the aims of payment by results.

105. Certainly the United Kingdom has no cause to he complacent about quality, either as a compstitor of the Americans or as a supplier to them. Although Americans to whom we spoke regarded British quality as generally high, they mentioned exceptions, notably in the equipment field, with some feeling. As customers, their dissatisfaction was increased if in addition they encountered indifferent spares support, as some of them did. To maintain stocks of spares, some of which may never be called for, either centrally or in regional depots, and to deliver them at high speed over long distances is a very expensive business for any company. The smaller the company the harder it is to rival the service provided for example by Boeing. However it must be remembered that Boeing's commerical aircraft division has not always been its present size, indeed it has grown something like eight times in the decade since the 707 was introduced into service.

106. While this growth has been assisted hy the substantial military orders which the American industry enjoys there can be little doubt that their success in delivering on time and their effective sales support have played no small part in winning new customers.

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107. In general, American commercial aircraft manufacturers appear to be very market conscious. We have no evidence however that their market research or direct sales activity is superior to, or more thorough than that done by British companies. On the other hand the quickness of American manufacturers' response to variations of specification requested by potential customers was contrasted by representatives of the airline we visited with the rather slower reaction they had experienced from British suppliers.

108. The airline also commented that a lack of confidence seemed to attend British projects. It was exemplified in the hesitancy which preceded decisions and it tended to infect potential customers. We say more about this subject in a later Chapter.

109. It is easy to appreciste the effect of this hesitancy on customers when one contemplates the very lsrge investment which for example Boeing have made in the 747 project. They have committed several hundred millions of dollars, not only to the design and development programme for the aircraft, but also to the erection of a brand new factory to undertake its quantity production. The factory has been built before the aircraft has msde its first flight. Such a visible display of confidence by the company in its own ability to carry the project through successfully can hardly fail to influence customers in their choice.

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SECTION III - THE TIMESCALE OF AIRCRAFT PROJECTS

CHAPTER 11 THE TIMESCALE OF DEVELOPMENT AND PRODUCTION

110. In the previous Section of this report we were concerned with the cost of various stages of a project. Although we have drawn conclusions about productivity from comparisons of manhours for particular jobs, we have not considered the actual calendar time which they take. The conclusions we have drawn from an examination of the records of a number of projects, and their implications for the competitive position of the British aircraft industry form the subject of this Section.

DEVELOPMENT

111. Development programmes for military and civil aircraft have certain basic features in common. In both, a period of intensive design leads to, and to some extent overlaps, the manufacture of one or more development aircraft which are used to study the handling and performance of the aircraft throughout its "flight envelope". Within this general frame, however, different relationships have evolved between the manufacturer and his military and civil customers.

112. Military development is, with rare exceptions, initiated after the Ministry of Defence have formally issued an Operational Requirement. This sets out in some detail the performance and characteristics of an aircraft or other piece of equipment which one or more of the Services needs to carry out certain military tasks. Until the end of the 1950's, it was customary for the Supply Department to invite competitive proposals for meeting the requirement. From those submitted, one (three in the case of the V-bombers) was selected and a contract placed for detailed design and manufacture of prototypes.

113. In the 1960's this procedure changed, partly because of the increasing size and complexity of projects and the merger of many of the competitors into larger groups to handle them, and partly because of changes recommended by the Gibb-Zuckerman Committee on the Management and Control of Research and Development. These changes did not alter the main feature which distinguishes military programmes. For military projects the sort of aircraft the manufacturer makes is determined by the customer, the Ministry of Defence. Before they accept the result into service, they satisfy themselves by means of trials carried out in conjunction with the Supply Department, that the equipment meets, or comes tolerably close to meeting, the Operational Requirement. The rare exceptions to this pattern are projects started as a private venture and offered to the Ministry of Defence at the prototype stage. Because of the great complexity and cost of present day aeroplanes, and the consequent high financial risk, few military projects now originate in this way.

114. Civil projects on the other hand are normally initiated by the manufacturer, although the details of the aircraft described in the Technical Specification are influenced by market research among prospective customers. If the Technical Specification is tailored very closely to the requirements of a single customer, it becomes for practical purposes very similar to an Operational Requirement.

115. Flight testing of civil aircraft also differs significantly from that of military projects. Acceptance trials are replaced by flight checks carried out by pilots of the Air Registration Board, who ascertain that the aircraft has an adequate level of safety in operation, and by route proving flights in conjunction with an airline in order to satisfy the Air Registration Board that its other requirements have been met, so that it may issue a Certificate of Airworthiness. The Air Registration Board is concerned only with safety in operation. This more limited aim and the fact that the Board is not in a contractual relationship with the manufacturer enable these trials to be more closely integrated with the later stages of the manufacturer's flight testing. Similar procedures govern military and civil development in the United States and other countries.

116. We have examined the time expended on the main stages of a number of aircraft developments, British and foreign, military and civil. Figure 6 compares civil aircraft developed in the United Kingdom, France and the United States since 1955. We have studied military projects in the same way. Some of the information about them is classified and it would be misleading to show it only for projects where it can be published.

/Figure 6

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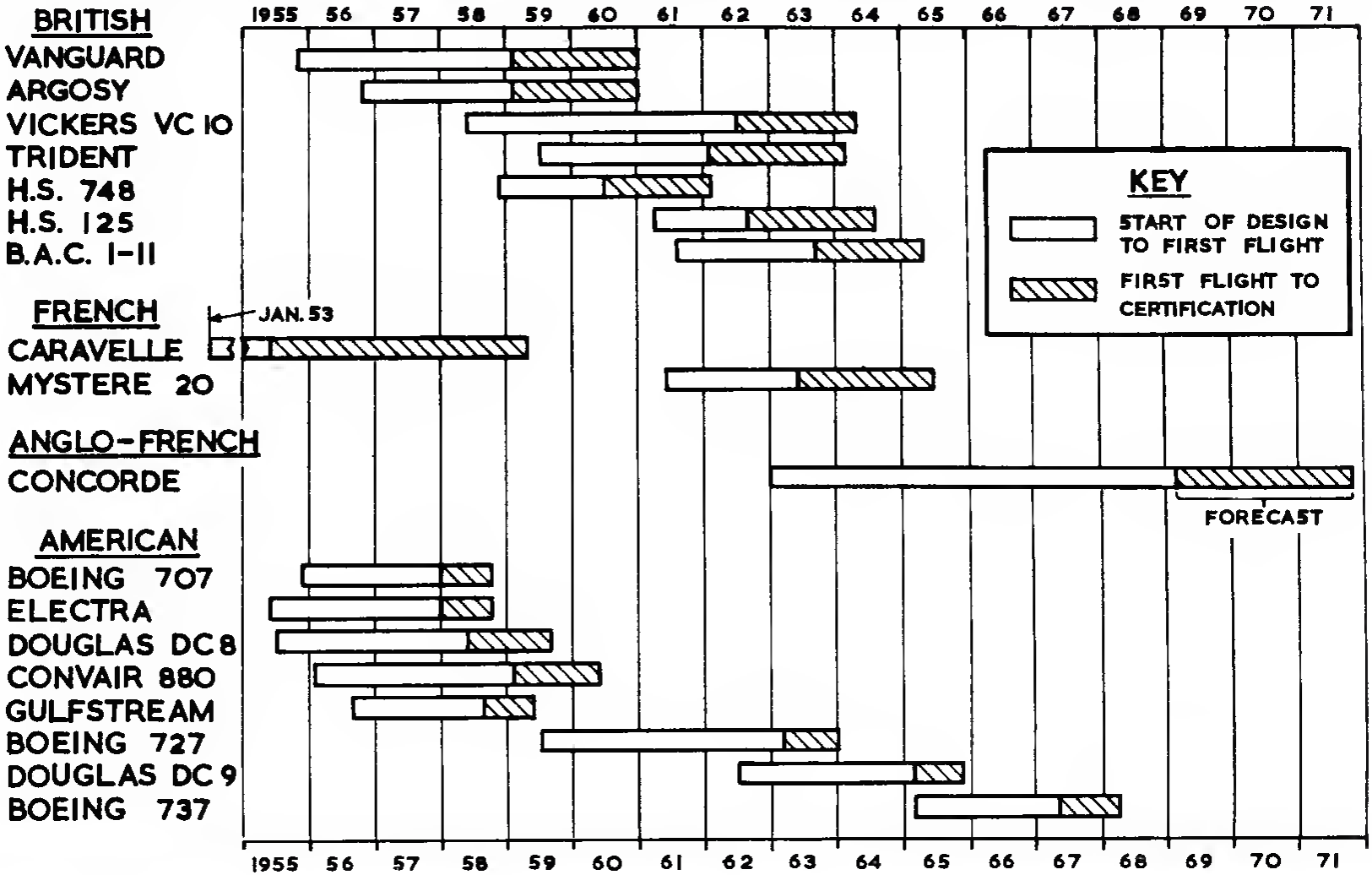
FIG. 6 – DEVELOPMENT & CERTIFICATION TIME FOR CIVIL AIRCRAFT



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The stages in the development we have taken are:-

(i) Issue of Operational Requirement to commencement of detailed design (military only: no civil equivalent).

(ii) Commencement of detailed design to first flight of a development aircraft.

(iii) First flight of development aircraft to release for service (military)/certificate of airworthiness (civil).

No two projects are exactly alike, nor does the terminology of different countries correspond precisely, and we felt there was little point in attempting to subdivide the stages more finely than this, because too much of the data would be subject to qualification. Indeed the events we have selected are not all as well and unambiguously documented as, for example, the first flight of a development aircraft, or the granting of a certificate of airworthiness. However we are satisfied that the data we have studied are accurate enough to justify our conclusions.

The average times for each stage of the projects in Figurs 6 are given in Table 6.

TABLE 6 AVERAGE DEVELOPMENT TIMES FOR CIVIL PROJECTS IN FIG. 6

	Design to first flight	First flight to C. of A.	TOTAL
U.S.	2 years 8 months	11 months	3 years 7 months
U.K.	2 years 6 months	1 year 10 months	4 years 4 months
France	2 years 2 months	3 years	5 years 2 months
Concorde (forecast only)	6 years 2 months	2 years 8 months	8 years 10 months

The fact that more recent British aircraft have had notably shorter times may be due to greater efficiency, or to the fact that they are smaller than the earlier types in the sample. The smaller of the two French aircraft took much less time than the larger, but the American projects show no correlation at all between the time taken and the size of the aircraft and have a much smaller variation about the mean. It is interesting to note that the shortest British test programme (1 year 7 months) was longer than the slowest American one (1 year 4 months). This is not true however of design and manufacture of the first aircraft; several British projects reached their first flight in a shorter time than some of the American aircraft. The French, though it is unwise to generalise from a sample of two, tend to accomplish the first flight earlier than Britain or the United States but to take much longer for development flying, which makes their whole programmes longer. The dates forecast for the Concorde are shown only for interest: it is a much more formidable technical undertaking than the other aircraft illustrated.

117. Military projects in both the United States and the United Kingdom take longer to develop than civil aircraft, as will be seen from Table 7 which gives mean times for a sample of twelve British and twenty-one American military aircraft of all types developed since the war. All the British examples, and many of the American, entered service several years ago; no new British "Mark 1" military aeroplane, i.e. one not adapted from an existing type has entered service in recent years. French military projects are harder to compare with British and American, because the French have derived a number of operational aircraft (such as the Mirage series) by progressive adaptation of an original prototype. Nevertheless the evidence we have seen indicates that although their prototypes fly sooner than British aircraft, the advantage gained from this tends to be more than lost through very much longer flight trials. Thus, from the Issue of a Requirement to entry into Service, French aircraft take longer than British.

/TABLE 7

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TABLE 7 AVERAGE DEVELOPMENT TIMES FOR AMERICAN AND BRITISH MILITARY PROJECTS

	Operational Requirement to Design Go-ahead	Design Go-ahead to First Flight	First Flight to Service Release	TOTAL
U. S.	10 months	2 years 9 months	2 years 8 months	6 years 3 months
U. K.	1 year 5 months	3 years 5 months	3 years 6 months	8 years 4 months

There was a much wider variation about the mean in both countries in the military sample. Both take 75-80% longer overall than civil projects, though about one-third of the extra time is accounted for by the decision taking in the defence departments prior to the issue of a design and development contract. If we ignore one American and one British project, for each of which this process took four years, this decision time is reduced to 8 months and 13 months.

118. The British achieve their first flight slightly earlier than the Americans for civil aircraft but American military aircraft make their first flight about 20 per cent earlier than British. Flight test programmes for both military and civil aircraft are accomplished in the United States in nearly 25 per cent less time, but in both countries military flight testing requires at least twice as long as civil certification, which underlines the difference between them already noted.

PRODUCTION

119. The lead time - the time which must elapse between the ordering of raw materials and components and the delivery of the completed aircraft to the customer - is the main determinant of the timescale of production. The lead time for complete aircraft is, of course, the resultant of a very large number of lead times for individual items which interact with each other. For this reason and others which we discuss later, it is normally measured in months or even years, rather than weeks or days.

120. It is usually desirable to arrange the manufacturing programme so that the first deliveries to customers are made as soon as possible after the completion of acceptance or airworthiness trials. This enables the manufacturer to preserve continuity in his factory between the construction of development and production aircraft, so that the experience gained in the former is exploited in the latter. At the same time it enables the customer to start operating the aircraft as soon as it has been cleared for the purpose. If this desirable goal is to be attained, it is necessary, because of the length of the lead time to take production decisions involving considerable financial outlay at a stage when development is far from complete, and in some cases before the aircraft has flown at all. Such decisions entail a considerable degree of risk: deficiences revealed during subsequent flight testing may call for extensive redesign and modification which, in turn, can have very wasteful repercussions on the production processes already completed. The situation is aggravated if the development programme gets behind schedule. For military projects a standard production aeroplane must be used for certain of the acceptance trials, and for the Final Conference at which the Service Department examines the aircraft for conformity to specification. These all tend to advance the date on which production commitments must be entered into and aggravate the effects on the programme of changes in the design during development.

121. Production commitments are, on the other hand, sometimes delayed because of the risk involved in ordering an aircraft in quantity until it has carried out at least a few successful flights. Manufacturers increasingly take this risk on the larger civil aircraft, the high cost of which makes it very attractive to use for development flight testing aeroplanes which can subsequently be refurbished and sold to customers.

122. We compared the production programmes of thirteen British and thirteen American military aircraft. The average time which elapsed between the placing of the first production order and the flight of the first production aircraft, was 32 months and 23 months respectively.

123. A similar comparison for civil aircraft is not possible because production commitments are entered into at the time when, or shortly after, design begins. The time-span of the first aircraft produced by quantity production methods is thus less accessible than for military projects.

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It also depends to a much greater degree on development progress and not merely on the time required for procuremsnt and manufacture.

124. In general, however, lead times are longer in Britain than in the United States for two reasons. Tbe smallness of initial batches is reflectsd in the orders for materials, components and other suh-contract work whicb the airframs manufacturer places on other suppliers. Hence the latter have little incentive to disrupt otber larger volumes of work for these small specialised orders with their stringent quality requirements. Nor does the prospect of follow-on orders necessarily stimulate them to give prompt service, hecause the total production quantity envisaged may not itself he very tempting. So it is understandahle if the suppliers are unwilling to put themselves out to offer early delivery. American airframe manufacturers, who can offer really worthwhile follow-on orders as a reward for performance on the initial batch, are in a much stronger position. Their initial orders tend to be larger too hecause they plan production at a higher rate from the start. The second factor which affects British lead times adversely is internal - both to tbe airframe manufacturer and to bis supplier. The British industry has so far heen generally less successful than the American in planning the flow of work through the production process. As a result, work has been held up for various reasons and the time from order to delivery is lengthened. We sball say more about production control in a later Cbapter.

125. So far we have spoken of the lead time at the start of production. The effect of learning and the build-up of production rate tend to shorten it. What may be termed the "marginal lead-time" - the delivery which can he offered against a new order once production is running at a stable level - is determined hy other factors as well, notahly the production rate itself and the extent to whicb the company is prepared to purchase materials and even start fahricating them speculatively in anticipation of further orders. Once again this depends on tbe size of total sales prospects.

THE BENEFITS OF SPEEDING UP DEVELOPMENT AND PRODUCTION

126. Although thers are exceptions, the United Kingdom finds it bard to matcb the times in which the United States develops, proves and delivers competing aircraft to service. This bas many undesirable consequences, most but not all economic. Sbortening the average total time taken from conception to initial delivery would do much to improve the salss of Britisb aircraft which is the first step to gaining the productivity henefits of larger quantities. Tbere are examples of civil aircraft developed on botb sides of the Atlantic whicb came into service too late to be profitable for thsir manufacturers or their operators. The market for them bad either heen captured by a competitor, or technical advances had already made them ohsolescent. This might be avoided if Britain's market rssearcbers could forecast requirements accurately further into the future than her competitors. Howsver there is no reason to suppose that they could do so. A less risky way is to develop and produce aircraft in a shorter time.

127. Shortening military development programmes and production lead time would primarily benefit exports: the Operational Requirement states wben a system is needed in service and no rewards are offered for delivery before people have been made available and trainsd to bandle it. It should not be inferred from this that there would he no domestic benefit from speeding up projects. The Ministry of Defence know roughly how far ahead they must plan new Operational Requirements, from experience of the time it takes to develop a new aircraft or other system. Ths role of military equipment is even harder to predict than for civil aircraft. Thus the shorter time they bave to look ahead the more likely the Requirement is to remain valid by the time equipment to meet it becomes available.

128. Britain can try to reduce the gestation time of new aircraft in a number of ways of which three seem to us to he the most promising. The first is to speed up Government decisions, the second to shorten the time taken for flight testing and the third to improve the production lead time. We discuss them in more detail in Chapters 17, 19 and 22 respectively.

/SECTION IV

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SECTION IV - INDUSTRY'S EFFORTS TO MEET THE CHALLENGE

CHAPTER 12 SOME RECENT IMPROVEMENTS IN PRODUCTIVITY AND EFFICIENCY IN THE AIRCRAFT INDUSTRY

129. In the years immediately preceding the period during which the Plowden Committee was collecting information on the aircraft industry, a large-scale reorganisation and rationalisation had been under way and this process is continuing within the larger industrial units thus created.

130. Ae in any large organisation, the advantages accruing from fundamental changes in the structure are not immediately apparent; the time lag before any improvements can be noted is measured in years. This is particularly true of the aircraft industry because many of the changes can only rationally be applied when new projects are introduced.

131. The fact that it has increased its output and the value of its exports in real terms speaks for the aircraft industry's awareness of the need to improve its efficiency and for the success with which it has set about doing so. More needs to be done, but we felt that before we went on to point out the areas which need to be changed or further improved, we should give some recognition to the steps which the industry has already taken on its own initiative to improvs its sfficiency.

132. We have received evidence from the major airframe and engine companies as well as from a number of equipment manufacturers, describing the efforts they have been making to this end in recent years. They are many and varied. From the summary of them which follows it will be apparent that although our enquiry stems from certain conclusions drawn by the Plowden Committee, the situation which gave rise to them has by no means remained static. Indeed, it has continued to change even while we have been studying it.

MANAGEMENT

133. The object of the reorganisation mentioned at the beginning of thie Chapter was to make the industry more competitive by enabling it to take advantage of economies of scale. All the major groups have developed central organisations for planning, forecasting, forward loading and allocation of resources, as well as financial planning which is closely related to all these matters and is mentioned again later. The introduction of these procedures has led to the closure of several of the smaller factories, which has reduced the number of establiehments used by the main airframe and aero-engine companies by 40 per cent of the 1955 figure. As a result, one major airframe company have been able to free some 6½ million square feet - 40 per cent of the total floor space they occupied after the merger. Another have closed two factories and concentrated the work at the remaining sites.

134. Within the factories which remain after such concentration, companies are redistributing work to make better use of their resources, though the factors mentioned in paragraph 130 and the availability of the necessary skills at suitable sites limit the rate at which they can do so. Where appropriate, special manufacturing facilities and activities such as heavy steel machining, or the production of engine blades, have been concentrated on one site. In other cases one factory or group of factories concentrates on related projects, such as military combat and training aircraft.

135. The smaller companies who were not involved in the mergers have also looked closely at their factory layouts and disposition and have made savings in floor space and manpower. One equipment manufacturer has freed some 50,000 square feet; another company have shut down one of their plants and will use only half as much floor space as they have vacated to handle the same volume of output.

136. In addition to this physical concentration, the large groups are also rationalising their procedures, so that work may more easily be transferred between factories. This standardisation and improvement of procedures has been encouraged by the development of management service departments, which by using the most relevant management techniques - many of them demanding the powerful digital computers that are now widely used by the industry - have improved efficiency in many areas. One company have estimated that the operations of their management services department have resulted in annual savings ten times the cost of the department. Improvements in staff education are continuing, with greater emphasis on training for managers and supervisors.

137. The Engineering Group of the Ministry of Technology has encouraged one large firm to make some of its computer training schemes more generally available - a tribute to the high standard of some of this training.

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138. Most companies havs developed their Project Management organisations considerably. The division of responsibility between Project and Line Manager varies according to local circumstances. Project management teams make extensive use of project planning techniques, including PERT. Accounting procedures are being changed so that cost and progress information can be readily related. One company told us that after they had introduced these techniques, they achieved a 30 per cent reduction in the development cost of one of their projects. The methods which arc being adopted are very similar to those advocated in the report of the Ministry of Aviation's Steering Group on Development Cost Estimating (see Chapter 16).

DESIGN AND DEVELOPMENT

139. It is clear that the industry has recognised the need to design for minimum production cost, and has taken steps to improve its ability to do so. All the companies who submitted evidence used Value Engineering techniques, and half of them have a formal Value Engineering organisation covering all the company's activities. They put the return on their investment in Value Engineering at between five and ten times its cost. Many firms, in addition to their Value Engineering staff, appoint Production Engineers whose special responsibility is to work directly with the designers from the start of the design. As part of their value engineering activity, a number of firms havs reduced the range of allowed materials and of standard parts. We deal in more detail with Value Engineering in Cbapter 18.

140. The industry is dsvoting more attention at the design stage to the reliability and maintainability of the product and most of the larger companies have established specialist groups to concentrate on these topics.

141. The industry continues to be a pioneer in the study, dsvelopment and exploitation of new materials, both metallic and non-metallic. It is often only some time after they have been developed for aerospacs use that they begin to be used by other industries. Aluminium alloys, high strength high temperature alloys, titanium, many adhesives, and a recent important example - carbon fibre composites - have all evolved in this way.

142. New ways of using the computer as a design tool are being devsloped. Its well-established role in carrying out technical calculations in aerodynamics, performance and structural analysis is being extended. In addition firms are developing mathematical models which enable them to simulate the behaviour of complete weapon and engine systems in a much shorter time than physical testing would require. Indeed it would often be impracticable to carry out equally exhaustive physical tests, so thst the computer offers the only way of establishing a high level of confidence in the product. An example of this is a mathematical model of the Lightning weapons system. It cost about £100,000 to prepare and provs, but has simulated some 4,000 sorties at a cost of only £50,000, which the company estimate is less than 1 per cent of the cost of real flying. It has thus made possible the evaluation of interception tactics against a background of information which would otherwise have cost millions of pounds. The effsct of modifications to various parts of the weapon system can also be assessed quickly and cbsaply. Analogue computer simulation of the flight control system of the Wessex III helicopter has saved many hours of flight development. Engine manufacturers also use these simulation techniques. Tbey can now assess the performance of a completely new engine in only a fsw days whereas previously the devslopment of special-to-type computer programmes would have taken several months. In general, by continually developing its design methods, and by taking advantage of the computer's increasing power, the industry has succeeded in containing the growing complexity of the design task.

143. Wben physical tests are carried out, for example in engine test beds, wind tunnels, structural test rigs or in flight, computers are widely used to speed up the analysis of the results of these tests and to present them in a readily intelligible form. Indeed, sometimes computer analysis can be carried out "on line", so that the results are available virtually instantly and can be used to direct the course of the tsst.

144. The availability of accurate large-scale automatic plotters has encouraged the development of computer-based methods of automatic draughting wblch enable drawings to be made by fewer draughtsmen in a shorter tims. Equipment firms are among the pioneers of these techniques: one of them has achieved a 20 per cent saving in drawing office time. Ways of using the output from this process as input to numerically controlled machines are already being exploited by the aero-engine industry and are being developed elsewhere.

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145. Finally, computers are helping the administration of design departments by maintaining up-to-date records of drawing lists, etc. As in the previous area, the importance of the link between such records and the corresponding records in production control is recognised and attempts are being made to take full advantage of the computer's flexibility.

MANUFACTURE

146. Almost all the firms who submitted evidence mentioned a variety of new manufacturing methods which they bad introduced, of which perhaps the commonest was the use of a wide rangs of numerically controlled machine tools. The industry bas already installed some 300 of them - 25 per cent of the total numher in use in the United Kingdom and an even higher psrcentage of the total value, since aircraft manufacture demands an abnormal amount of complex machining. They have reduced manufacturing time by as much as 75 per cent. Special machine tools and associated computer programmes have heen developed to meet the industry's needs and these machine tools are now heing exported to other European countries and the United States.

147. Similar savings in inspection time have been made by the use of a wide variety of automatic inspection machinery. Some of the equipment manufacturers have developed their own equipment for this purpose.

148. The aero-engine and equipment companies have also installed a good deal of more specialised plant to perform such operations as high speed broaching, electro-chemical machining, electron beam welding, bydraulic forming and tangential form grinding, to name but a few. Tbese new techniques are already being used by many companies, hut the industry, notably again the equipment and engine sectors, is continually evaluating other new methods and indeed playing a considerable role in their development.

149. All the companies wbo sent us evidencs have, during the past few years, made a growing investment in the development of computer-based production control systems, a subject with which we deal in more detail in Chapter 22. Their systems are being developed in such a way as to inter-relate the previoualy fragmented activities of ordering, stock control, progress, etc., although the extent to which they have carried the process varies considerably. Even though completely inter-related systems bave not yet been developed, significant advantages have been obtained from the introduction of sub-systems, for example to control stock. It is now possible to producs a complete schedule of the materials, bought out items and manufactured parts for a helicopter in three bours, whereas previously it took eight man-years of clerical effort.

150. After-sales support of the product is a major task in the industry and here again the computer has been used to develop integrated spares procedures covering all activities from initial provisioning through to delivery of spares to customers. These procedures have, in some cases, reduced the amount of effort required within the industry and, we understand, within Government Departments as well, hut the major advantage has been in the improved support enjoyed hy the customer.

FINANCIAL CONTROL

151. Each of the major groups has developed financial planning and control procedures which cover the organisation's activity for the following five to ten years. It is clear that they are paying great attention to reconciling project-based and function-hased plans. This long term planning forms the basis for major decisions on manpower, capital facilities and finance. Within this frame the work is broken down in progressively greater detail in such a way that it can be readily related to the other project and departmental control procedures already mentioned. Computers enable actual expenditure to he reported more quickly so that it can be promptly compared with the budgets.

152. The development of these control procedures and the improvsment in estimating methods will, we believe, assist the related objectives of incentive contracting and early prics fixing to which so much attention is already being given.

153. As mentioned elsewhere in the report, outaide purchases account for a high proportion of the cost of production. The industry has tightened its control over its suppliers through the development of improved vendor rating schemes, and has also taken advantage of bulk buying. Another large element in the total cost of production is labour cost, and companies are reviewing their incentive schemes for hoth direct and indirect personnel. For the latter, recently developed techniques for measuring indirect work have heen widely used and have yielded improvements in productivity as large as 20 per cent.

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154. Thus some of the right steps are being taken. Our recommendations draw attention to those which we consider the most important. The reasons why it is so vital that these measures should be pursued as widely and vigorously as possible form much of the substance of Section V of this report.

/SECTION V

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SECTION V - MEASURES TO MAKE BRITISH PROJECTS MORE COMPETITIVE

CHAPTER 13 THE IMPORTANCE OF QUANTITY

155. In Sections II and III of our report we have compared, as precisely as the information available to us allowed, the performance of the British aircraft industry with that of its main competitor, the American industry. By one frequently used measure of productivity, value added per man-year, the Americans are roughly three times as productive as this country. This is true of manufacturing industry generally in the two countries.

156. It is unfortunate that this ratio lends itself to misinterpretation as a measure of the relative efficiency with which the British and American industries carry out their respective tasks. Such an inference ignores what is overwhelmingly the largest single determinant of productivity, at least in the aircraft case, namely the quantity produced. We have shown that if American aircraft had been produced in the same quantity as most British projects, they would have cost about twice as much as they actually did. Not three times as much, because in some ways American manufacturers are undeniably more efficient than British and this offsets some of the former's labour cost disadvantage. For the moment however we are concerned only with the effect of quantity.

157. The effect of longer production runs and higher rates of manufacture is not limited to the average unit man-hours. Aircraft projects have very substantial fixed costs, for example the initial development programme and tooling as well as many overhead expenses which do not change much with quite large variations in the quantity of aircraft produced. These costs all have to be recovered by adding an element to the selling price of the aircraft. As production quantity increases, the fixed or quasi-fixed costs can be spread over a larger number, so that they represant a smaller slement in the unit selling price, which can correspondingly be made keener.

158. For these reasons we conclude that the most important step towards raising the productivity of the British aircraft industry is to ensure that projects are produced in quantities large enough to reap the benefits of the labour cost advantage. The aircraft produced must, of course, also be sold. Thus the main effort must be directed at capturing for the United Kingdom a larger share of the world aircraft market than it has had in recent years. It is with this aim in mind that our recommendations have been framed.

159. We have regarded them as falling into two complementary groups. For convenience we label them respectively strategic and tactical. The strategic measures are those which are more appropriate to projects which are not as yet under way. Tactical improvements can be applied equally well to all projects. The analogy implied by the labels should not be pressed too far. Argument about the classification of particular items is possible, but largely irrelevant, since we doubt that the application of either category without the other would produce the desired results.

160. The strategic measures we deal with in Chapters 14 to 17. They cover choice of projects, the need for a reasonably stable basis for planning, the role of collaboration, estimating, the control of cost, and project management. The tactical measures which follow in Chapters 18 to 22, deal with a number of more detailed improvements which we believe must be made in order to reduce costs, ensure timely delivery, and increase the confidence of potential customers.

/CHAPTER 14

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161. If Britain is to sell its aircraft in larger numbers than it has done hitherto, it must clearly start by choosing the right projects. In general a new project should only be started when firm prospects of sales are large enough to make its development economic and its selling price competitive. This principle would seem too obvious to require enunciation had it not been so frequently disregarded in the past.

162. In this Chapter we define some of the factors which should influence the selection of projects for development. Although we illustrate them by reference to different types of aircraft, we have not attempted to define the successful aircraft of the 1970's. This is a task for experts with more time and more detailed information about market requirements than we could command. We limit ourselves to stating some of the principles which ought to guide their choice. We deal first with civil aircraft because we believe they will form the largest part of the industry's production in the future and because economic considerations largely determine the selection of civil projects, whereas their influence on decisions about military aeroplanes is smaller.

CIVIL AIRCRAFT

163. The first thing to look at is the total world market for the class of project contemplated, extending from the earliest date at which it can be offered for service to the end of its ultimate development. The demand for most kinds of aircraft - large and small, long-range and short-range - is expected to continue growing in response to the rapid increase in the demand for air travel predicted for the foreseeable future. The rate of expansion will vary with the class of aircraft: the market for long and medium haul aircraft with more than 200 seats is expected to grow fastest, to form the largest and most valuable section of the market as operators are able to exploit the economies of scale associated with ever larger aircraft. The growth expected in the market for medium and short-haul aircraft (i. e. with range up to about 3,750km.) is illustrated by Figures 7 and 8, prepared by the Ministry of Technology.

164. A study of future demand by itself provides little help in arriving at a decision on what type of aircraft to undertake since almost any new aircraft will enter an expanding market. The next consideration must be the strength of competition to which it will be exposed.

165. Most of the competition comes from across the Atlantic, but rivals for smaller aircraft are now starting to emerge in some western European countries and Japan. Competition is most formidable at present in the market for large subsonic aircraft, where American firms have entrenched themselves very strongly with long-haul operators. Furthermore they are already developing two medium-haul aircraft to carry 300 or more passengers which will compete to some extent with the proposed European airbus, although the latter has been aimed at a different sub-section of the market. In the supersonic field the work so far accomplished on the Concorde gives it at present a clear lead. Smaller British aircraft such as the BAC 1-11, HS 748 and HS 125 have gained a good foothold in their respective markets. Future projects may aim to increase this penetration or exploit it by a "family link" with their successful forerunners, as Boeing have done in selling their 707, 727 and 737.

166. A project's success in challenging competitors is strongly influenced by its timing. Are the resources to develop and build it and the industry's experience of the technical problem of the proposed type of aircraft adequate to enable it to be ready for service when operators require it, and as quickly as, or better still ahead of, any direct competitors? Can this date be met without detriment to other projects in progress or contemplated? Every opportunity should be taken to exploit a lead already gained in some technique such as vertical take-off and when this is done Britain must take care that the technical advantage it gives her is not lost because competitive projects are developed more quickly.

167. The most important factor of all is probably the selling price of a product in relation to numbers sold. The larger the numbers the lower is the average manufacturing cost (because of "learning") and the smaller the amount which must be added to the selling price of each aircraft to cover the development and other launching costs.

/Figure 7

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FIG. 7 - TENTATIVE FORECAST OF WORLD REQUIREMENTS FOR AIRCRAFT TO OPERATE ON MEDIUM AND SHORT-HAUL MAJOR ROUTES (< 2000 n.m.)

(i.e. EXCLUDING THOSE OPERATED IN 1965 BY TWIN-ENGINE AIRCRAFT WITH LESS THAN 50 SEATS)

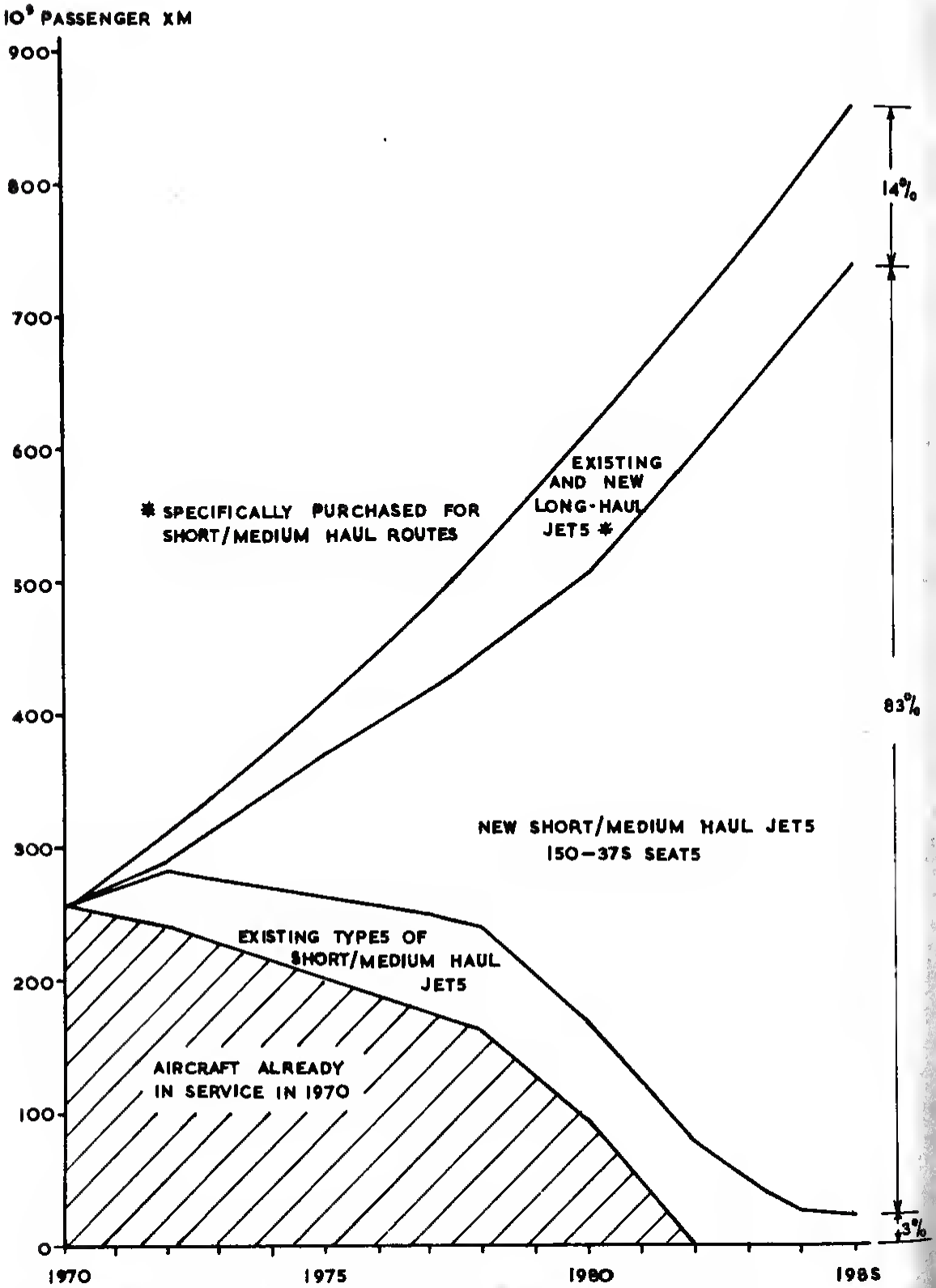

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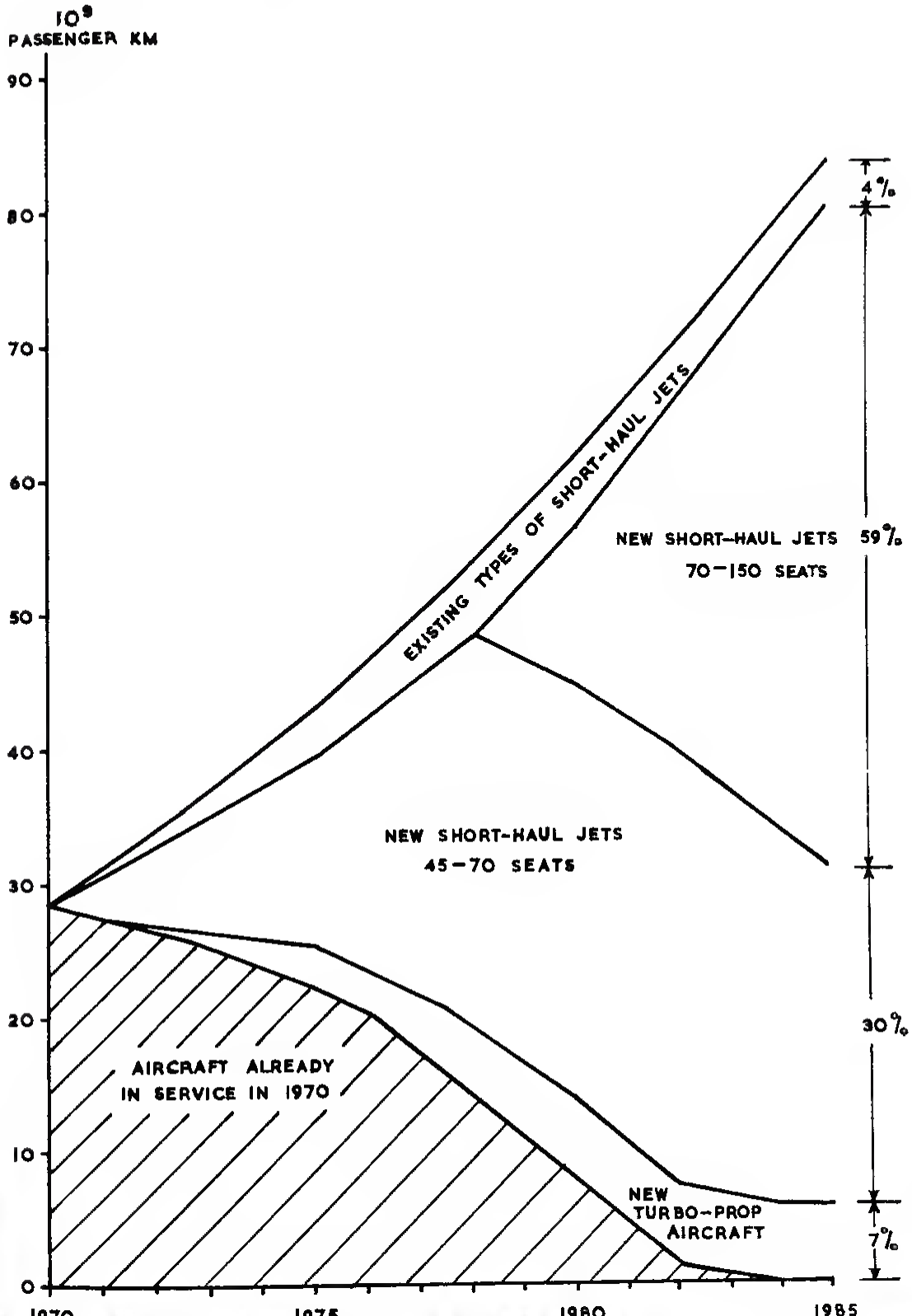
FIG. 8 – TENTATIVE FORECAST OF WORLD REQUIREMENTS FOR AIRCRAFT TO OPERATE ON SHORT-HAUL MINOR ROUTES (<1000 n.m.)

(i.e. THOSE OPERATED IN 1965 BY AIRCRAFT WITH 15 – 50 SEATS)



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168. Exceptionally there may be occasions where a project has no effective competition, perhaps due to a temporary technical lead. The selling price can then be pitched high enough for it to break even with a short production run. Such instances however are rare, and normally the selling price is determined by world competition. It is then a question of determining how many aircraft must be sold in order to break even and how many more are needed to give an adequate return on the funds invested.

169. Figure 9 illustrates the effect of quantity and research and development cost on the selling price for a hypothetical project assuming three different levels of R & D expenditure. The lowest, broken curve represents the cumulative average production cost of the aircraft for various quantities up to 400. It is similar in shape to a learning curve, to which it is of course related. (A learning rate of 90% has been assumed in this example). The distance between this broken line and each of the three solid lines, A, B and C above it represents the amount which must be added to the production cost in order to recover R & D cost of (A) £50 million, (B) £100 million and (C) £200 million respectively, over various quantities. For an aircraft the production cost of which was of the order shown these sums might correspond to the following kinds of project:-

(A) the development of a new mark of an existing aircraft;

(B) the development of a new subsonic transport;

(C) the development of an advanced aircraft representing a major step forward in technology.

In each case research and development is assumed to take four years, its cost being spread accordingly, and production deliveries are assumed to begin a year after it ends, continuing for five years. The selling price includes an allowance for spares and a return of 8 per cent on the funds invested in R & D. It is important to note that it is the ratio of R & D cost to unit production cost which is important and not their absolute value. The magnitude of R & D cost ought not of itself to deter Britain from undertaking advanced aircraft projects, provided that the cost estimates and sales forecasts can be relied upon. An upper limit will of course be set by the proportion of the country's resources (both financial and technical) which can reasonably be devoted to the development of a single project.

170. Figure 10 compares the cost of developing and manufacturing a high performance subsonic aircraft in Britain and in the United States plotted against quantity. The lower, solid line is based on the actual costs, extrapolated as necessary for the higher quantities, while the upper, broken line shows the cost of building the same aircraft in the United States, which has been predicted by the Rand Corporation's cost estimating formulae. American labour rates have had to be assumed and a production rate double the British output has been used.

171. It illustrates the important point that the competitive advantage to this country due to its lower labour costs increases with the number produced. For example, if Britain builds 50 aircraft, the United States need to build 130 to offset their higher wages. If Britain builds 100, the United States must build 300, while if Britain builds 150 the United States would have to build nearly 500 to achieve the same unit cost.

172. This increasing ratio is due to the changing slope of the learning curve, and as a result a comparatively small increase in the number of aircraft built would put this country in a much stronger position relative to the United States than it is in now. We believe that at a time when the demand for air transport is doubling every 10 years, this fact is of considerable importance for the future competitive ability of the British industry.

173. We deal with cost estimating in Chapter 15. We have also considered the adequacy of the industry's marketing. Airframe and engine manufacturers have their own market research organisations who are responsible for predicting future trends in world aviation, assessing global needs and recommending the kinds of market to enter. Their sources of information are numerous. Company staff are in regular contact with potential customers and their reports are supplemented by a wide variety of statistical and other information obtained from associated companies and agents overseas, British civil air attaches, research and consultancy organisations, and aeronautical and commercial literature. From this information they obtain a picture of the past growth of air traffic and its probable future trend, political, economic and commercial factors likely to influence the aviation market, the specific needs of individual operators and the thinking and future competitiveness of other manufacturers. When they have analysed this information the

/Figure 9

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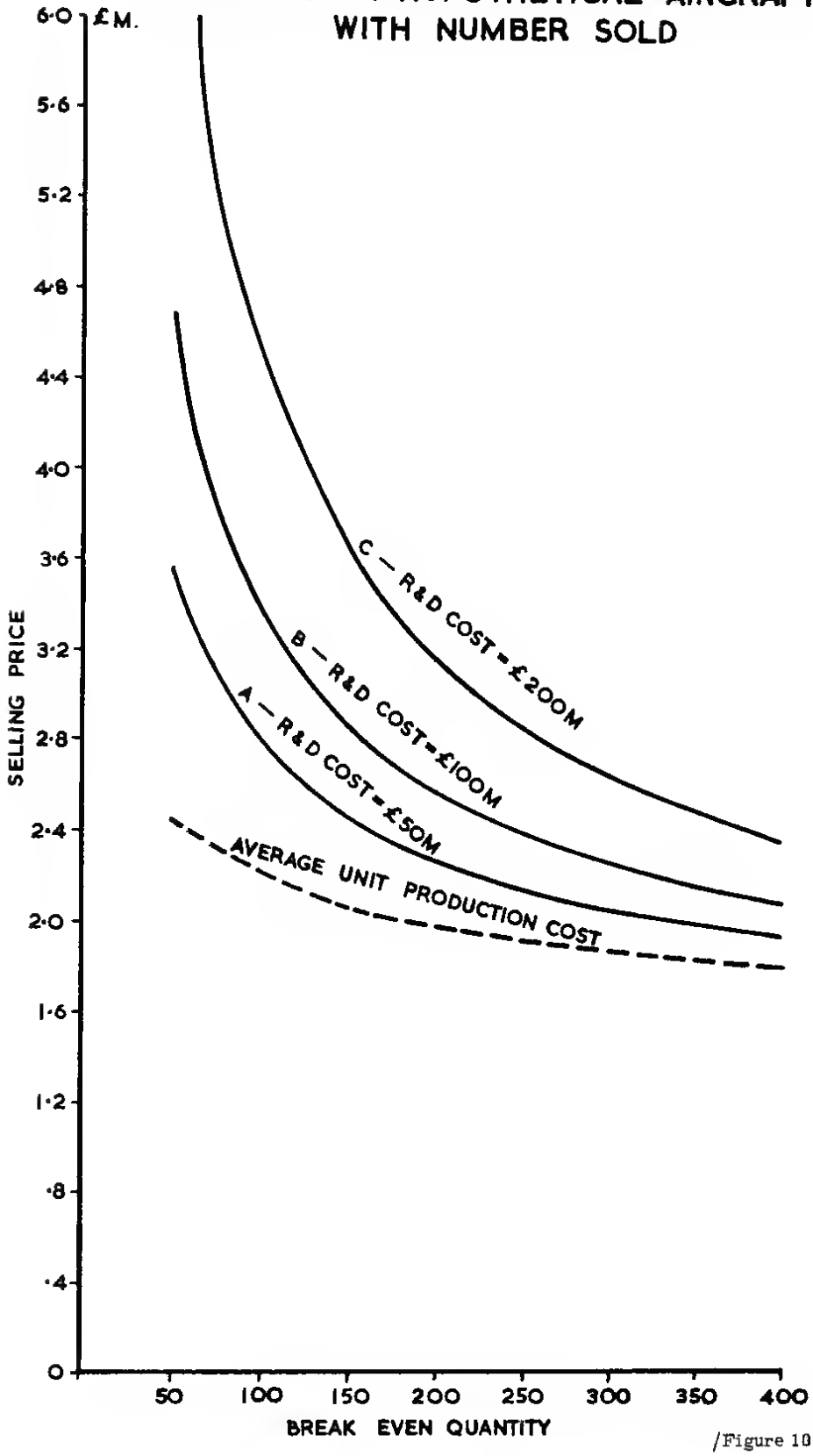
FIG. 9 – VARIATION OF BREAK EVEN SELLING PRICE OF A HYPOTHETICAL AIRCRAFT WITH NUMBER SOLD



/Figure 10

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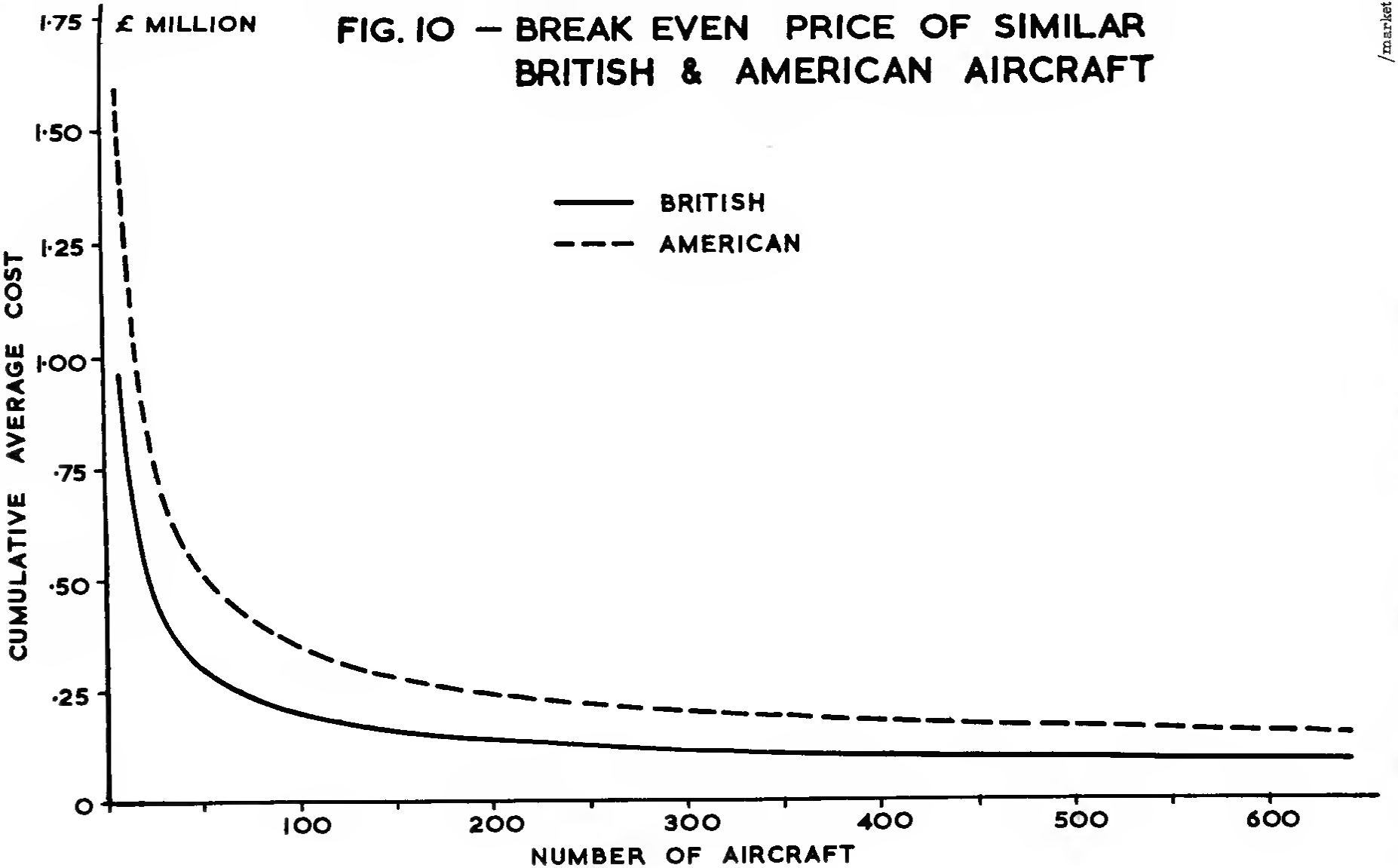

FIG. 10 — BREAK EVEN PRICE OF SIMILAR BRITISH & AMERICAN AIRCRAFT

/market

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market research organisation pass the results to management, sales staff and project engineers to assist them in planning and marketing the company's future projects.

174. We have compared this with the research undertaken by one of the most successful American companies. So far as we were able to judge they look at the same subjects in similar depth. They have the benefit of a wealth of statistics compiled in accordance with Government requirements on the passenger traffic of individual American airlines. No counterpart for them exists in this country. It would be advantageous if the similar statistics of the traffic of the main British carriers could be made available to the British aircraft industry. Apart from this we were not struck by any obvious gaps in the activity we have described. In the past however the disappointing sales of some projects, although thsy had many contributory causes, were at least partly attributable to poor market research. The lesson has been learnt and the industry now undertakes this task much more carefully and thoroughly than it did formerly.

175. Aircraft have sometimes been made less generally attractive because they were too closely tailored to the needs of BEA or BOAC. We pointed out in Chapter 3 that initial orders placed by American airlines were normally large enough to guarantee a project a reasonable chance of success and that the American domestic market as a whole is big enough to sustain it subsequently. British orders for civil aircraft are unlikely to be large enough in the foreseeable future to do either of these things. Hence before a project can be regarded as an acceptable risk it is almost certain to need the support of one or two firm orders from abroad. To secure them the manufacturer must include features that will appeal to his most interested foreign customers. It is a mistake to pay insufficient regard to the latter's requirements because of a too exclusive preoccupation with those of domestic customers, however important these may be.

176. The debate on whether the airline corporations should be required to buy British aircraft lies outside our terms of reference. An initial order from a large British airline helps to establish a firm base for production, and the industry regards the experience British airlines can contribute to drawing up the specification as very valuable. However we have not encountered any evidence which shows that s domestic order for a civil aircraft commends it to foreign buyers in the way that a military order undoubtedly does. On the contrary, with the sole exception of the Viscount, the British civil aircraft which have been most successful since the war have been those which have not been bought by the Corporations at all, or at least not until they were well established in production.

177. The reasons for this have been exhaustively analysed and it would serve no purpose to rehearse them here. However much manufacturers may welcome an order from a nationalised airline, economically it is of the same value as an order of similar size from any other customer, domestic or foreign. Hence when the specification of the initial Mark of a project (which will inevitably be a compromise between the different ideas of the initial buyers) is drawn up, the demands of a domestic airline should receive no greater weight than those of other customers, unless it is prepared to place firm orders for a larger quantity.

MILITARY PROJECTS

178. Ideally the criteria we have set out for civil projects should also be applied to military projects. In practice we recognise both the difficulties of doing so, and also that the most saleable aircraft are not necessarily the best for Britain's own defence needs. Nevertheless in providing for the latter Britain cannot afford to neglect the export potential of the aircraft chosen because the domestic market for them is so small in comparison not only with that of the United States but also of Sweden. The Governments of both those countries have found the means to continue to order military aeroplanes in economically worthwhile quantities despite their rapidly increasing complexity and cost, but Britain lacks the resources of the United States and has to allocate those she has among more numerous and more varied demands than Sweden. The latter offers some useful lessons, but we doubt that however well they are applied, they can bring about a situation where British defence orders for a particular aircraft are sufficiently large to justify developing it on purely economic grounds. in any case other considerations will always influence the decision whether or not to develop a new military project. It may be important to remain independent of foreign sources. New techniques developed and proven for military aircraft and engines for them yield valuable benefits later in the civil field. To explore them in the course of a civil project would frequently be uneconomic and it is hard to believe that a civil aircraft industry could remain competitive technically in the long term without this backing from military work, particularly if its rivals enjoyed this advantage.

/179.

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179. Furthermore, experience has shown that other countries are very chary of committing themselves to ordering military equipment for their Forces until the Government developing it has placed its own production order. The reason probably lies in the difficulty of evaluating it: the worth of military aircraft and weapons, unlike that of civil aircraft, is not measured primarily in terms of operating cost, profitability, or customer appeal, but in much less tangible terms. The knowledge that a domestic order has been placed inspires confidence that the development will be pursued to a successful conclusion and yield a worthwhile product.

180. A fixed ceiling has been imposed on total defence expenditure and there are many competing demands for these limited funds. Since the larger the quantity produced, the lower the unit price can be, it is obviously very much in the interest of the Services to frame their Operational Requirements in a way which will make the systems designed to meet them attractive also to other countries, and to encourage the confidence of foreign customers. By placing orders for production of an aircraft at the earliest possible date, the Ministry of Defence would strengthen the confidence of foreign customers in the project.

181. At the highest levels in the Ministries of Technology and Defence the wisdom of the first of these principles is certainly recognised. It is of the utmost importance that this intent be clearly communicated to the subordinate levels at which Operational Requirements are drafted. The inclusion of features which make a system attractive to foreign buyers may entail the sacrifice of others which appear more desirable for the British Services. Reluctance to make this sacrifice for the sake of foreign orders which at that stage are highly speculative is understandable, but failure to take account of these export possibilities may make the equipment much more expensive than it need be. We therefore consider it important that those who actually undertake the drafting of Operational Requirements should be briefed much more fully on the features which the Ministry of Technology and the industry have found through their market intelligence organisations to be most attractive to foreign buyers.

182. In the past the Services have been understandably cautious about ordering equipment at an early stage in development, before either its performance or cost have been reliably established. This difficulty could be overcome by the conscious application of better project definition and cost estimating procedures which we describe in Chapter 16. Properly carried out they should provide the Ministry of Defence with sufficient confidence in a project to commit itself to production at a much earlier stage with great advantage to foreign sales. It is this display of confidence which the potential foreign buyers await.

COLLABORATION WITH OTHER COUNTRIES

183. In recent years Britain has attempted to solve the twin problems of growing cost of development and reduction in numbers produced by undertaking both civil and military projects jointly with other countries. The primary aims of such collaboration are to share the burden of research and development cost, to enlarge the potential market for a project and to obtain some of the benefits of greater quantity. Governments are rarely willing to contribute substantial funds for development of an aircraft unless they expect their Forces or national airlines to equip themselves with it in due course.

184. From statements which have been made to us we have formed the view that because of these undoubtedly attractive features, insufficient attention has been given to the effect on industrial efficiency, not of collaboration per se, but of the way in which it is promoted and carried out.

185. The initiative in these projects has so far been taken by the Governments of the countries concerned. They are naturally anxious to ensure that they receive an equitable return for their investment in the form both of a final product which adequately meets their country's needs and also of work for their aircraft and associated industries. This may entail prolonged negotiation over, among other things, the specification of the aircraft and the sharing of work on the project.

186. In their efforts to arrive at a satisfactory common specification it is natural for collaborating countries to be preoccupied with their national needs. Export sales are, however, no less important for such projects than if they were undertaken nationally. Although the combined production orders for a collaborative project may be large, so are the industrial resources among which the work must be shared. While each country's industry gains some of the benefits of quantity which we described in the last Chapter, it does so only for a fraction of the total work. Moreover, collaborative projects by their nature tend to be large and/or technically ambitious.

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Their development costs are therefore likely to be high and if they are not to be merely written off, part of them will have to be recovered from export orders in the same way as for a national venture.

187. Because considerations of national prestige and of balancing the financial contribution of the participating countries, rather than of efficiency, appear to determine the way in which work is shared between them, only by chance will the division of tasks be technically felicitous. Yet if the work, whether development or production, is allocated from other considerations than those of technical efficiency, it must inevitably cost more than it need. The main criticism which we have encountered on this score concerned the allocation of orders for equipment used in collaborative projects.

188. Airframe manufacturers have become more and more accustomed to sub-contract work to other companies. The trend is more marked in the United States where whole sections of a wing, fuselage, or tail unit may be not only produced but designed by a sub-contractor who moreover bears a share of the risk of the project. There is no basic reason why it should be less efficient technically to do the same thing across national frontiers: the difficulties arise from language and distance, they are not primarily technical. However when the independent manufacturer sub-contracts work he is guided by considerations of economy: he finds it cheaper to offload work, and part of the financial risk, than to expand his own resources (both capital and human) to cope with a transitory peak in his workload. Manufacturers participating in a collaborative programme have to share the work between themselves not as dictated by their own capacity, but in proportions imposed upon them by the agreement between their Governments.

189. There may be considerable delays while questions of this kind are being resolved, so that the project takes a long time to gather momentum. In Section III we showed how important time is in this competitive field, and that European countries generally take longer than the United States to get an aircraft into service. The addition of any factors which tend to prolong this time can only weaken the prospects of the project from the start, particularly if the work has also been divided in a way which leads to a larger than necessary number of interfaces demanding more liaison and increasing the administrative cost.

190. There is a further danger that collaboration in a virtually captive European market may insulate European partners from the healthy effects of competition and lead to requirements tailored for too small a range of potential buyers. We also have some sympathy with the view that Britain's partners of today may become the competitors of tomorrow, when they have fortified themselves technically through contact with the most experienced aircraft industry in Europe.

191. In setting out these disadvantages as we see them, we are not criticising the policy of collaboration in development and production of aircraft. Except insofar as it affects efficiency it would not be proper for us to comment on it. Our criticism is concerned with the way in which that policy is being implemented. We have not been able to investigate this in depth, but we believe that better ways can be found of exploiting the benefits of international collaboration without weakening the British aircraft industry's competitiveness, but preserving and advancing its technical expertise. It may be that it can only be really effectively achieved if the initiative in seeking opportunities and negotiating such partnerships is taken by the industry itself, stimulated and encouraged by the Ministry of Technology. For civil aircraft we believe it is both feasible and the right objective, though its accomplishment will call for a more uniform policy towards launching aid on the part of the Governments concerned. For military aircraft, it is Governments who state the Operational Requirements and it is probably inevitable that they should continue to lead in the promotion of new joint ventures.

192. We recommend that the Ministry of Technology should review critically their experience of collaborative projects and seek ways of implementing the policy which are more compatible with efficiency and speedy execution of the work.

/CHAPTER 15

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193. The comparisons described in Section III of our report revealed that in Britain civil aircraft take about 4 years from inception to certification, while a military project on average spans twice this period. We have pointed out the advantages of shortening this gestation period and in later chapters we suggest some ways of doing so. But however thoroughly they are applied, the time-scale of aircraft development will still be measured in years rather than months.

194. This long cycle time and the variety of activities contributing to it pose formidable problems to the industry in the planning of its manpower and capital investment. Fluctuations in manpower requirements throughout a project's life are illustrated in Figure 11. It shows how the number of design engineers (in the upper graph) and manufacturing labour (in the lower) varies throughout the total life of a typical military airframe project. The small team of designers engaged on feasibility and project studies rapidly expands once full development is authorised. Tooling and manufacture of development aircraft necessarily lag behind until the designer's work begins to crystallise, and the peak rate of production is not reached until some time after the initial deliveries begin. Design effort overlaps the first part of production, to deal with modifications and "stretch" of the basic aircraft, or the development of new marks.

195. The manufacturer is faced by an alternation of peaks and troughs in his requirement for both types of manpower - engineers and draughtsmen on the one hand, shop floor workers on the other. The extent to which his capital facilities are used varies in the same way. If a new project is started just as the manpower employed on an earlier one begins to decline, the labour which becomes redundant can be largely absorbed, so that the trough is kept to a minimum. The longer the interval between the start of successive projects the fewer the people who can be offered continuity of employment hence the deeper is the trough. The ideal interval is five or six years. Much longer or irregular gaps produce much larger variations between the peak workforce and the minimum. They also foster inefficiency because managements are reluctant to lay off skilled employees with long experience and tend to retain the best of them, even though there may not be sufficient work to justify doing so.

196. At the start of a project, whether it is civil or military, the manufacturer has to estimate the cost of all this manpower and his standing costs for several years ahead. He cannot heap all his standing costs on the one project or it will become hopelessly uneconomic; he must therefore assume that other projects will be started in the future which will share the burden of these costs and help him to maintain the size of his work force at a fairly constant level. Like any other producer he must also make assumptions about the number of his products he will succeed in selling, and the accuracy of his cost estimating depends partly on the accuracy with which he predicts his sales. In this the aircraft manufacturer is perhaps no worse off than many other producers of complex equipment, but the inevitable uncertainty which they share is made worse for him by his dependence on Government decisions for the new projects on which he has budgeted.

197. The advances which have taken place in aircraft design in the last two decades, as we have pointed out in Chapter 3, have meant that they have to last longer and are replaced less often. Hence new projects are likely to be started at wider intervals than in the past. Consequently if a new project fails to materialise when expected, the planning and costing done several years previously will be upset. Unfortunately the manufacturer in Britain has practically no control over the starting date of new projects of any size, because he depends so heavily on financial support for them from the Government.

198. If the Government decline to support a civil project or to order a new military one at the time the manufacturer expected them to, his work load declines and the cost of the work he has in hand inexorably rises. Civil aircraft are usually ordered at fixed prices, so the contractor may make a heavy loss as a result. If prices have not been fixed for the military development or production he has on hand he will seek to charge more for it. Faced with an increase in the cost of work on contract, and with the problem of accommodating it within the funds available, the Government may react by reducing or deferring their orders or by cancelling some of them outright. Any of these actions reduces the industry's workload still further (and it must be remembered that its repercussions are felt not only by the main contractor, but by his many sub-contractors and other suppliers too) and adds still more to the cost of the remaining work. This is because although some of the manpower engaged on the cancelled or deferred work can be shed many of the indirect costs associated with it cannot.

/Figure 11

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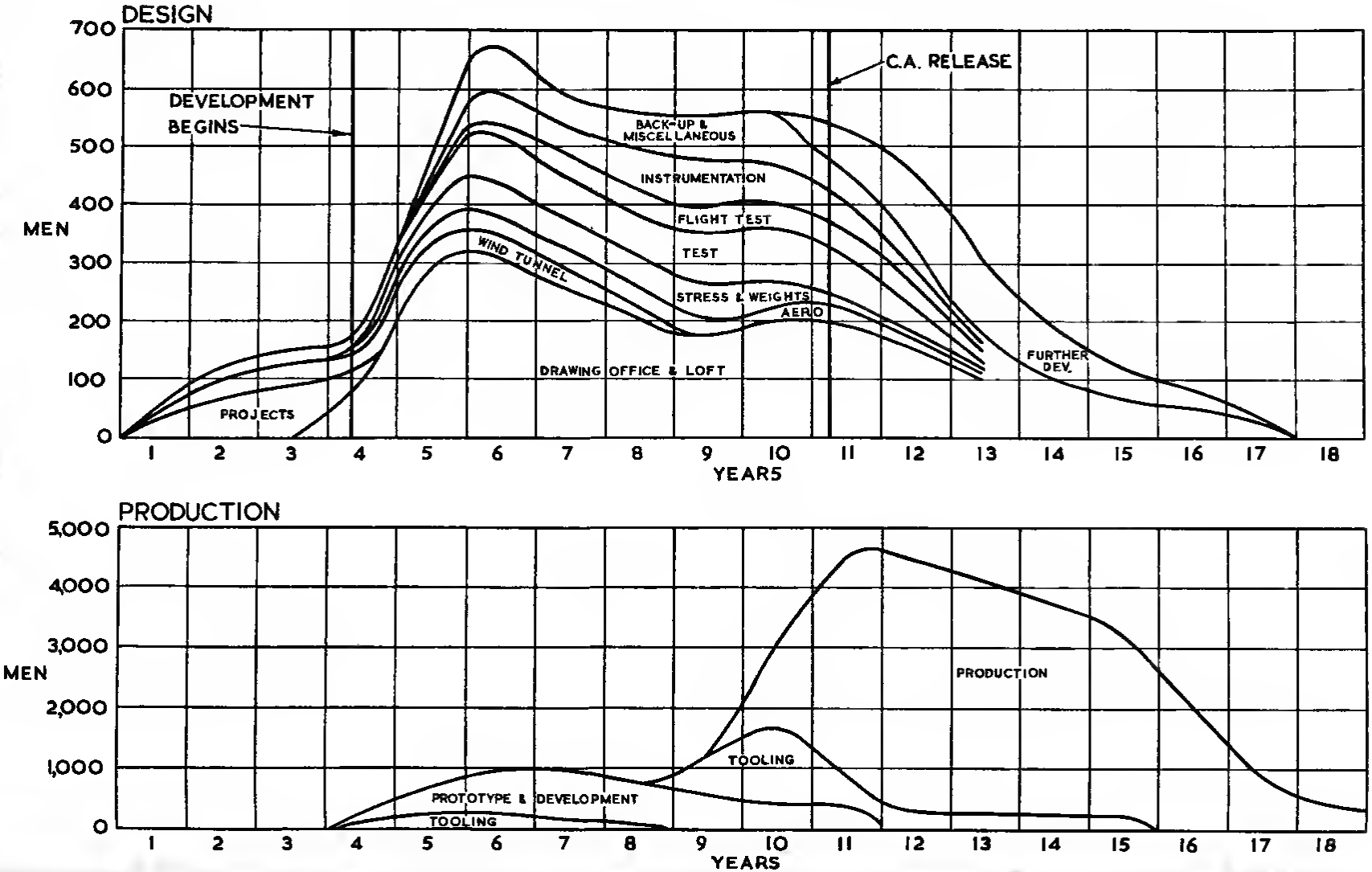
FIG.11 - MANPOWER FOR A TYPICAL MILITARY PROJECT



199. Consequently stability is of paramount importance to the industry's planning and estimating. It is important to all industries, but the long timescale to which the aircraft industry works intensifies its need for a stable basis for forward planning. How is this to be attained? It has been suggested to us that within the Ministry of Technology a Planning Organisation should be set up to analyse requirements in the defence, civil aviation and space fields, both at home and abroad, and plan the deployment of the available resources to meet them. Its head would report directly to the Minister and it would include representatives of the other Government Departments concerned with this task. The Planning Organisation would initiate research, and formulate the overall development and production programme, including private venture work, allocating priorities as necessary; but day-to-day management of programmes once approved would remain with the existing Controllerates of the Ministry of Technology.

200. We sympathise with the underlying aim of this proposal. We do not, however, believe that it would be practical, or even desirable, to divorce from each other the responsibilities for planning and executing the programme. Decisions on military projects must inevitably lie with the Ministry of Defence. Realistic plans can only be prepared as an integral part of the everyday functions of the Ministry of Technology and we feel that the proposal we have described underestimates the attention which is now given by this Department and by the Government to the long-term implications of policy decisions.

201. The Transport Aircraft Requirements Committee has begun to concern itself increasingly with detailed long-term market surveys and with establishing priorities in the civil field. The latter task has long been undertaken for military aviation by the appropriate Ministry of Defence committees, on which the Ministry of Technology are represented. Thus part of the work proposed for the Planning Organisation is already being done.

202. Within the Ministry of Technology a very detailed ten-year forecast of the loading of the industry is now prepared periodically. It is compiled from estimates of future loading prepared by all the branches throughout the Department who are directly concerned with development and production. They provide estimates of expenditure and manpower, project-by-project and year-by-year, for as far ahead as they can see, adding their assumptions for later years as the current work tails off. Information on commercial sales prospects is available to some extent within the Department, but the major airframe and engine companies are being brought into this exercise and asked to submit their own forecasts. From all this information, there emerges a composite picture of the total expected loading of the industry over the following ten years. It is based necessarily and increasingly in the more distant years on explicit assumptions. It is available to assist Ministers and their Departments in the consultations which precede decisions on new major aircraft projects, so that the effect of these decisions on the industry can be assessed. We welcome the effort which the Ministry, aided by the Industry, are making to forecast the latter's future loading. It is essential that the Government, whose decisions have such a long-term effect on the industry, should have a clear picture of their implications.

203. We have considered whether it would benefit the national aircraft effort to make this forecast public. It might help to allay the doubts which have grown up in recent years about the industry's long term prospects. It could not however do very much more. It would not be in the industry's interests to reveal its confidential sales plans to its competitors, nor in the country's to disclose in any detail its expected expenditure on military development and procurement. Furthermore it must be remembered that it is a forecast, not an executive plan. Such a projection, to the extent that it involves Government or indeed industrial spending cannot involve firm commitment. The funds derived from Government spending depend on annual approval by Parliament of the Department's estimates, and though financial controls established in years gone by for very different purposes are not always compatible with the long time span associated with activities such as aircraft development, it does not fall within our terms of reference to consider fundamental changes in this regard.

204. It is our present understanding that while the Government are concerned to ensure that all practical steps to improve the efficiency of the aircraft industry are taken it is their practice to take decisions on projects on their individual merits. Whatever forecasts may be provided as a background for these ad hoc decisions, the industry's workload and employment at any time is simply the sum of the separate projects then in progress. This does not necessarily result in an adequate measure of stability.

205. We submit that no commercial company could hope to survive long in a competitive market if it limited its top policy decision-making process to consideration of the development of individual

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projects as they mature for decision, and if it had no overall long term policy. In the United Kingdom the Government and the aircraft industry are to a large degree in partnership, certainly as regards the larger aircraft, in one of the most competitive of the world marketa and they need an overall policy if their combined efforta are to achieve the best result. It is not for us to recommend what that policy sbould be - but we can say that in the absence of a clear long term policy it cannot be expected that questions for decision will be posed in the right terms, that the best decisions will be taken, or that an adequate measure of stability in design loading and production can be achieved.

206. If the Government and the industry accept the need for, and can formulate an agreed long-term policy objective which lends itself to clear long-term planning we would recommend that a bigh level group sbould be appointed from Government and industry to work out a plan for achieving it. Short term decisions could then be taken as part of a progression towards the long-term objectivs. We appreciate that such a plan would need to be continuously up-datsd and modified in the ligbt of many factors - particularly the degree of success or failure of individual projects. This is no different from the situation in any large scale enterprise although, because of the nature of the aircraft buainess and the cost of launching a major project, the incidence of major changes would probably be greater. However, ws believe that the very size of these cbanges adds to the importance of having back-up plans ready to cope with aa many eventualities as can be foreaeen. The undoubted difficulty of the task is not a valid reason for not attempting it.

/CHAPTER 16

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207. In the last Chapter we emphasised that disturbances in a programme of large long-term projects affect not only the immediate items cancelled or curtailed, but many others as well. Hence without stability, cost estimates cannot be expected to remain valid throughout such disturbances.

208. One of the chief causes of disturbance to the aircraft industry's programme in recent years has been the unreliability of cost estimates. It would be pure wishful thinking to suppose that stability can be maintained if the cost estimates on which planning is based are subject to frequent and significant increases. In recent years such increases have unfortunately been far from rare occurences in aerospace development and production not only in the United Kingdom but in other countries as well and few projects have been free from them.

209. We believe that there are three reasons for the unreliability of cost estimates in the past. The first is that initial estimates were prepared with inadequate attention to and knowledge of the technical problems likely to be encountered during projects, the second that the requirements for weapon systems called for too much technical advance at one time, and the third is the concept of an "acceptable" cost.

PROJECT STUDIES AND PROJECT DEFINITION

210. The former Ministry of Aviation set up an investigation into the first of these problems a few years ago. It was supervised by a Steering Group led by Mr. W. G. Downey, one of the members of our Committee. The Steering Group's Report, completed at the end of 1966, blamed the inadequacy of project studies for the poor initial estimates of project cost. In a number of cases analysed for the Group the time and effort devoted to the project study had been substantially less than that envisaged by the Gibb-Zuckerman Report on the Control of Research and Development. The Steering Group felt that studies more thorough than that Report advocated were the only means by which technical uncertainty could be reduced to the point where the task of development might be defined, and its cost estimated, comprehensively. Unless this was done, those managing the development could not, as work proceeded, compare actual technical progress and cost with their estimates - or at least not with any precision. If they could not do that, they could not determine the consequences of any proposed changes in the technical programme, nor the reason when costs were found to be exceeding expectations.

211. We endorse the Steering Group's recommendations and hope that the detailed Code of Practice which it drew up will be adopted generally for Ministry of Technology projects. It is already being employed on some new projects, and many firms in the industry have themselves devised systems of project control which resemble the Code very closely. They have pointed out that the detailed analysis of the work which the procedures call for requires considerably more effort and expense than has been devoted to project estimating in the past. It is therefore less economic for smaller items of development than for large. This was a criticism which the Steering Group anticipated and it devised an abridged procedure appropriate for smaller projects. It is important that there should be flexibility in the application of these new procedures. If they are applied rigidly the cost of complying with them for smaller pieces of development work could be disproportionately heavy.

212. Given the long time-span of development work in this field, it is too early yet to assess the effectiveness of the new procedures. It is to be expected that it will increase as both the Ministry and the Industry gain more experience in applying them. Their accuracy will, however, also be determined by how well the project definition stages of new projects succeed in their purpose. Their success in turn depends on two things: the degree of technical innovation called for in a project and the comprehensiveness of the Operational Requirement itself.

213. The Ministry of Aviation Steering Group recommended that one of the objects of the Project Definition phase should be to explore in greater depth the areas of above average technical risk. The aim should be to reduce their uncertainties so that their subsequent development may be defined accurately and its cost estimated with confidence. This will only be practicable if the high-risk areas are comparatively few. Past projects have placed heavy reliance on new and advanced sub-systems, such as engines, navigation and weapon equipment, which have all had to be designed and developed in parallel. To reduce their technical uncertainty to the required level would call for a project definition phase rivalling in extent and cost the development phase proper. We believe that in undertaking advanced projects in the future Britain should learn from Sweden

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and make the best use of her limited resources by depending as much as possible on proven technology. This does not mean that new projects should eschew all novelty, but that the areas of ambitious advance should be more limited than in the past when airframe, engine and equipment have frequently all been developed in parallel to a very advanced specification. It is already the policy of the Ministry of Technology to make greater use of incentive contracts and this decision has been welcomed by the industry. Unless the definition and estimating of new projects is approached in the way we have described, there can be little hope of attaining the level of confidence in cost estimates which is necessary for the negotiation of incentive contracts. Hence the Ministry and industry should avoid where possible any action which impedes the establishment of this level of confidence.

THE OPERATIONAL REQUIREMENT AND TECHNICAL SPECIFICATION

214. It has been suggested to us that large increases in cost estimates in the past have usually been due to repeated revisions by the Ministry of Defence of their Operational Requirements. Our investigations have shown that this is not so, although the idea has gained wide currency. With the exception of one or two projects (of which one was cancelled) Operational Requirements have remained very stable despite the rapidly changing political environment of the 1950's and 1960's and the technical advances in the armouries of potential adversaries. They seem however to have lacked comprehensiveness. Too many details have been left to be filled in later, perhaps only when the contractor seeks clarification during development. The information he is given then may call for extensive redesign or raise other technical problems which are expensive to solve and were not allowed for in the original estimate.

215. Examples of such amplification of the Operational Requirement occur even during a Final Conference. This is held for every military aircraft, to enable the Service Department and the Ministry of Technology to check physically that it fully meets the Technical Specification into which the latter have translated the Operational Requirement. During the course of the Conference, which may last a week or more, Ministry of Defence representatives raise numerous requests for modifications to overcome problems they foresee in the operation or servicing of the aircraft. They arise partly because of genuine oversights by the contractor or the Ministry of Technology. They also occur in relation to matters not covered by either the Operational Requirement or the Technical Specification. In other cases they spring from changes in decisions already taken. Many of the individual modifications are quite small, but their cumulative effect is more serious, particularly because they have an immediate disruptive influence on the production line which is usually just getting under way.

216. Both the Ministry of Technology and the Ministry of Defence have told us that they regard the Final Conference as indispensable. This is probably true in the present state of definition of projects: although the main purpose of the Conference is to check "compliance with specification" many of the requests for change concern details which do not appear in the Operational Requirement/Technical Specification at all, nor in the Ministry of Technology's Manual, "Design Requirements for Service Aircraft". A modern aeroplane is a complicated compromise between many conflicting ideals. It is only to be expected that when several dozen experienced aircrew and engineers examine it closely they will find many things they feel could be improved.

217. Nothing akin to the Final Conference exists in the civil field. A witness from BEA with previous experience of military projects told us that the airline would avoid a procedure of this kind at all costs. At the same time he emphasised that they were careful to define the aircraft they were buying in great detail in their contract specification. Some of the details are changed (but not in general amplified) by means of formal contract amendments as detailed design progresses and mock-ups are appraised, but the extra cost of them is agreed by the customer. Thus by the time the aircraft is ready to enter service only a very formal acceptance check is necessary.

218. We recognise that to the extent that military aircraft are technically more advanced than civil types it may be difficult to define them in this way. Nevertheless we believe that much can be done to make Operational Requirements and Technical Specifications more comprehensive at an earlier stage in the project, ideally during the Project Definition phase. This may have to start with a Requirement expressed in rather broad terms, indeed it is probably desirable that it should begin in this way. The new type of Project Definition phase should enable the detailed implications of this broad requirement to be clearly and fully identified before development begins. The details should not be left to be filled in later by specialists who have no responsibility for the

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cost of the project as a whole. We believe that here again the Swedish approach has useful lessons, but before considering them we must mention the third factor in bad cost estimating.

THE NOTION OF ACCEPTABLE FIGURES

219. We believe that an important influence on estimates of cost prepared in the past has been the concept of figures which would make projects "acceptable" to those responsible for approving their development. Once a project had been authorised on the basis of such an estimate there was a very good chance that if its cost increased further funds would be made available. Cancellation was unlikely since it wasted the money already spent and did nothing to meet the Operational Requirement.

220. If the unpalatable truth had been faced, many ambitious projects would have been stillborn. Some of those which were started, however, were ultimately cancelled, with nothing to show for the expenditure of tens or sometimes hundreds of millions of pounds. It is hard to believe that the country and the industry would not have employed their resources better, and been better served, by undertaking more practicable projects which they could afford to carry through to completion.

LESSONS OF THE SWEDISH APPROACH

221. The Swedish Air Force regard cost as one item, perhaps the most important, in their Operational Requirement. They do not devise a high-performance weapon system first and then obtain an estimate of cost. The specification and the cost go hand-in-hand from the start. The Operational Requirement is drawn up by the Air Force, in consultation with the Air Force Board, in terms of the performance that can be achieved within the defence funds approved for the project in principle by the Swedish Parliament. The Air Force Board is assisted in advising the Air Force by its airframe contractor. Thus there is little scope for the pursuit of the ideal, particularly since all three parties are aware that the sum approved, subject only to adjustment for inflation, is all that will be available. If they cannot keep the cost within that limit, the project will almost certainly be cancelled.

222. It is inconsistent to impose a rigorous ceiling on the defence budget as a whole without exercising similarly firm control of the major areas of expenditure within it. We believe that before authorising full development the Government's objective should be to determine a firm cost limit which they are prepared to pay for the development and production of a future project. If the pitfalls described in paragraphs 219 and 220 are to be avoided the figure must be a realistic one, arrived at with the advice of the main contractor or contractors involved. Once laid down, it must be adhered to as rigidly as possible. If costs show signs of exceeding the agreed limit, they should normally be contained by trading performance or production quantity. The limit should be revised only because of inflation or some unavoidable grave setback such as can never be ruled out completely in advanced development work, however thoroughly the basic research has been done. The cumulative effect of many minor problems should not be regarded as grounds for revision.

223. It might be argued on the basis of past experience of the magnitude of cost increases that such a discipline would in practice result in a totally unacceptable degree of degradation in the performance of the system. There is a danger of this happening until it has been firmly impressed on all concerned with the estimating of project cost that it is intended to make cost an overriding consideration.

224. Such an outcome is not inevitable if Project Definition is approached in a cost conscious way. This means that the Operational Requirement must be stated as comprehensively as possible by the end of the Project Definition Phase, not as an outline to be filled in at a later date. The Technical Specification and the concept for meeting it should make use of established proven techniques and systems. The Americans have done this by developing what they style "building blocks". These are usually pieces of equipment, systems or components exploiting new techniques and designed when only a general rather than a specific application is foreseen for them. When a new project is planned it is able to incorporate some of these "building blocks", which will already have been constructed and tested to some extent. This is obviously a less risky method than developing all the interdependent parts of a technically advanced and complex weapon system from scratch. Ideally we should like to see this approach adopted by the British Government, but we realise that the extent to which it can be is severely limited by the funds available. Britain cannot afford the luxury of developing building blocks for which no application is afterwards found: in choosing them she must have fairly specific projects in mind which will make use of them. A somewhat similar

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result can be achieved however by staggering the initial design and development of airframes, engines and other systems, so that there is at least a measure of confidence in the capability of some of the main elements before they are integrated into a complete new system. This might be done for example by carrying out the initial design and testing of an engine or navigation and attack system before beginning work on an airframe in which they are intended to be used. Another approach, which has been used for the Nimrod aircraft, is to develop an existing airframe with well-proven flight systems, and to install in it new and more advanced operational equipment. This enables the areas of high technical risk to be reduced and explored more thoroughly during the project definition phase, so that detailed and conscientious estimating of the development task can be undertaken.

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225. Our comparison of the timescales of British and American military projects, described in Chapter 11, revealed that the Americans are a good deal quicker to authorise development once they have issued their Operational Requirement. All the British projects which we compared were started before the Gibb-Zuckerman Committee on the Control of Research and Development reported in 1961, so that the issue of the Operational Requirement for each of them was not preceded by the formal feasibility study, nor followed by the formal project study, which that Committee recommended. In fact no entirely new British aircraft project has been started since the Gibb-Zuckerman procedures were adopted, though they have been applied to some guided weapon projects and to aircraft derived from existing aircraft types.

226. It has been alleged to us that the division of the project into these discrete stages, aimed at clarifying the technical and financial implications of the development before substantial resources were committed to it, has caused delay in the authorisation of work, prolonged projects and increased their cost. No evidence however has been produced to justify this assertion, which seems to confuse the concept with the way it has been executed. Breaking down a development programme into several stages, each of which must be expressly authorised by formal decisions of the Ministry of Technology, Ministry of Defence and the Treasury, affords a ready opportunity for protracted debate. The Gibb-Zuckerman Committee recognised this danger and did its best to forestall it. It recommended that a decision whether to proceed to full development should normally be made during the final three months of the project study, so that the contract for full development might be placed immediately the project study phase ended. Exceptionally, when a decision could not be reached in that period, work should continue on a short-term holding contract adequate to allow the project to proceed and gather momentum at the same rate as it would during the initial part of a full development contract. By this means the timescale of the project, established in the project study, would not be jeopardised.

227. We agree with the view that a holding contract may be unavoidable in these circumstances, if the team assembled during the project study is not to be allowed to disperse to other work. However we have encountered criticism that in practice holding contracts have in the past been exploited as a convenient opportunity for deferring decisions, and at the same time as a measure to hold the project team together at the lowest possible cost rather than as the dynamic stage envisaged by the Gibb-Zuckerman Committee. We note with approval that the situation has now greatly improved. The few holding contracts still in existence await only the agreement of prices before being replaced by formal contracts. The more thorough project definition phases advocated by the Steering Group on Development Cost Estimating should provide more dependable information and hence make it easier to reach decision. But they will still culminate in the same type of decision so that opportunities for hesitation and delay will still exist. The procedures provide no safeguard against these dangers and it is for the Department to ensure that they are avoided.

228. We recommend that early in their consultations on a new project the Ministries of Defence, Technology, and the main contractor should define the key decisions which must be taken before succeeding stages of the work can be authorised and the latest dates by which they must be taken if the system is to enter service on time. The contractor must play his part by providing timely technical information and cost estimates to those responsible for taking the decisions. Any failure to reach a decision by the due date should be reported to the three parties at a senior level together with estimates of the consequences in terms of delay in the availability of the project to the Services and the effect on cost.

PROJECT MANAGEMENT BY THE MINISTRY OF TECHNOLOGY

229. The Ministry of Technology have inherited from their forerunners, the Ministries of Supply and Aviation, a large organisation which oversees the development and production work undertaken for them by industry. It is responsible for specifying the work to be done and interpreting this specification; monitoring the technical and financial progress of the work; co-ordinating the development and production of equipment procured by the Department from specialist firms for use in the project; obtaining and administering funds for the project; dealing with policy matters concerning it and negotiating the contracts under which the work is carried out by industry.

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230. Until recently these tasks have been allocated to separate headquarters branches, each with a functional specialisation. Thus one branch handled most of the technical aspects of research and development, another those of production, a third dealt with finance and policy, while another handled contractual negotiations. Each branch might deal with one or more projects depending on their size. The need for continuous co-ordination between these separate branches, each in a different hierarchy, has led in recent years to experiments in integrating the financial and technical responsibilities for development in a single team under a Project Director. Contractual matters continue to be handled separately by specialists; so does production except for the Concorde.

231. The complexity of a modern weapon system demands a very wide range of technical expertise. Special technical knowledge is required to manage the development of an aircraft engine, a rocket motor for a guided missile, or complex electronic equipment, and they may be used in more than one weapon system. Further specialist branches have grown up in the Ministry of Technology to handle these items as more or less self-contained "sub-projects". The Project Director has only a co-ordinating responsibility for them, and their financial and contractual aspects may be handled by branches different from those dealing with the projects in which they are used.

232. The separation between the various branches has been accentuated by their division into three distinct hierarchies which converge only at the Secretary (Aviation), the official head of the Aviation Group. Under him the technical branches are presided over by the Controllers of Aircraft (CA) and of Guided Weapons and Electronics (CGWL), while the non-technical branches form a separate family headed jointly by two Deputy Secretaries, (one of whom is responsible for military projects, the other for civil). A project as complex as an aircraft, or a large guided weapon system involves branches in each of these three hierarchies. The project teams set up in recent years have gone some way towards reducing this division between lines of responsibility, though they have not eliminated it. They report jointly to a Deputy Secretary and a Controller.

233. The headquarters organisation is supported by scientific advice from the Department's various research establishments, whose role differs in the two Controllerates. They play a more active part in guided weapon and electronics projects than in aircraft development.

234. The problems of specialisation by function, which we have described here, or by product, are not peculiar to the Ministry of Technology. They are also encountered in industry except in the rare instances where an entire factory is engaged exclusively on one project. In the more usual situation where several products are under development or in production simultaneously, a balance has to be sought between the advantages and disadvantages of each type of organisation, since the good points of the one tend to be the weaknesses of the other. If each project team is self-contained, with experts in all the necessary disciplines, the man in charge is in a very strong position to ensure that his subordinates adopt the single-minded approach desirable for the successful accomplishment of the work. The disadvantages of organising teams in this way are that total resources are not used with maximum efficiency: some duplication of effort is unavoidable, particularly because exchange of information between teams on different projects may be inadequate. On the other hand if the expertise in a particular discipline is concentrated in one place, to provide a specialist service to various projects, these disadvantages are replaced by another. Conflicts of priority arise from time to time and project managers must then compete for the resources they require. In practice both industry and the Ministry of Technology are finding that some compromise between the two forms of organisation is the best solution and are combining functional specialisation with the appointment of project managers who have varying degrees of executive authority.

235. The Ministry of Aviation took some steps in this direction a few years ago by combining the technical and financial administration of certain development projects under a single director of senior rank. Previously a Technical Director could not authorise the expenditure of project funds, but had to obtain the approval of the finance branch for it.

236. We have taken evidence from Directors of projects organised in this way and in the older way and we have also heard the views of the Ministry of Defence and industry on the effectiveness of both types of management. There is general agreement that giving the Project Director both technical and financial responsibility for a single project as head of a team containing both technical and administrative staff has significantly improved his authority and effectiveness and been beneficial to the projects concerned. We have little doubt that there would be advantages

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in extending this type of amalgamation of responsibilities and staff not only to future projects but also to other areas of the Ministry's aviation work where it is practicable to do so.

237 Although the new Project Directorates have made a promising start we feel that they still have some weaknesses which need to be overcome. Project Directors have hitherto had no responsibility for production, (except in the rather special case of Concorde) nor for contractual negotiations about their projects, and they still depend for various sub-systems on other specialist technical branches, some of them in a different Controllerate.

238. There are several arguments against making the Project Director responsible for production proper. Production activity continues long after development activity has dwindled virtually to nothing (even when this activity is extended by the development of new Marks and by post-development services). This is much longer than the need for a Project Director exists. There will always be a continuing need for a central production division to handle the multitude of small items not large enough to be regarded as "projects". Experienced production engineers are in short supply and the best use can be made of those available if their employment is centralised. If they were allocated to project teams to advise the Project Director, it would be difficult to find enough staff, and the centralised activity would be deprived of talent. These are formidable problems. Nevertheless in other parts of this report we lay considerable stress on the need to weigh development and production considerations within an overall budget, and on the importance of keeping production cost firmly in mind at all stages of design and development. Project Directors are already concerned with production methods to a limited extent. They are responsible for the procurement of aircraft for acceptance trials, some of which, although their number is small, are usually made by quantity production methods. Similarly the Director of a Guided Weapons project sometimes procures the comparatively large number of missiles required for evaluation trials (though by no means invariably: they have often been handled by the Director of Guided Weapons Production). This is now being taken a stage further; Directors of certain new guided weapon projects are being made responsible for the initial production quantity as well. We welcome this innovation because we feel that unless the Project Director is made responsible for at least the initial deliveries of his project to the Services, he will find it hard to resist the temptation to pursue technical refinement at the expense of ease and cheapness in production. The important words are "made responsible". He will require the advice of staff from the Production Division. Although it helps communication if such staff are close at hand, we do not regard it as essential that they should be located alongside the Director, or even that they should be exclusively engaged on his project. Provided that the Director is answerable for the initial production deliveries, including their cost, and that the nominated production staff are answerable to him, there is no reason why, time permitting, other production activities should not have the benefit of their expertise.

239. Some of the arguments apply to contract negotiation as well. The Contracts Division has formal responsibility for authorising a contractor to undertake work for the Department - neither the technical nor the finance branches are permitted to do so. The requirements of public accountability and the virtual absence of competition for many of the Department's orders combine to make the negotiation of these contracts a complex and protracted task. A long time may elapse between the issuing of financial authority and the actual placing of the contract. Although the contractor is sometimes authorised to proceed with the work while the contractual negotiations are progressing, some delays do occur. They are compounded if there are competing priorities in the Contracts Division and if various parts of a project are handled by different Contracts branches.

240. While there might be some advantage in integrating the contract negotiators in the project team, to deal with all items affecting the development, we accept the Ministry of Technology's view that the advantage is outweighed by the disadvantages which would go with it. Since there are only two major airframe companies and one engine firm, it frequently happens that one of them is dealing simultaneously with substantial Ministry contracts for different projects. If Project Directors were responsible for negotiating the contracts for their individual projects there would be a real danger of inconsistency, and even conflict, in policies and procedures. Moreover in view of the intense interest shown by Parliament in this field, there is value in having an organisation with a special responsibility for safeguarding the position of the Accounting Officer, and in giving the organisation a measure of independence. Contract negotiations involving substantial sums demand senior staff with considerable experience and it would be impossible to find adequate staff of the right calibre to second to each project for this purpose, particularly since a strong central division would still be needed to handle the multitude of items too small to rank as "projects" purchased by the Department. However, the Contracts Division, while retaining

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its expertise centrally, has taken an important step in making some of its staff responsible for all aspects of a single project, so that contracts for an airframe and its engines or equipment are all handled by the same contracts officers. Indeed staff as senior as Deputy Director in the Division devote practically all their time to a single project where this is sufficiently large. We have been assured that those contracts officers engaged in this kind of work regard themselves as members of a team which includes the Project Directorate. Working relations are very close and the only distinction is that in the last analysis these staff are not subject to the Project Director's direction in contractual negotiations.

241. Even on technical matters the Project Director does not always have full executive authority over all the equipment which forms part of his project. Some of its components and sub-systems - aero-engines, rocket motors for guided weapons, navigation equipment for example - will call for special technical expertise, or be common to more than one project, or indeed may fall into both these categories. There have grown up, in order to handle them, specialist branches which pool the necessary expertise and co-ordinate requirements when a piece of equipment has several applications. These branches have their own chains of authority; sometimes they do not respond to the same Controller as the Project Director. This has produced an anomalous situation in which the latter depends very heavily on the timely availability of the specialists' equipment, yet often has no executive responsibility for, or authority over, its development. If it is not available when the project requires it, the whole programme may be delayed and its cost increased.

242. Where financial as well as technical responsibility for the complete project has been vested in the Project Director, this has done much to overcome the problem. This practice has not yet been generally adopted in the Ministry. We hope that it will be, because we believe that ideally the Project Director should have financial control over and be responsible for all parts of his project. He will still need the expertise of speciallst branches even with the greater use of "building blocks" which we advocate. For larger items, such as an aero-engine, the specialists might be seconded full time to the Project Director's staff, though for the smaller ones they will have to divide their time between pieces of work under development for more than one project.

243. We have also considered the length of time for which Project Directors serve. It is clearly unreasonable to expect them to stay with a project throughout its life, which could be as long as twenty years, nor would there be enough work for them once it was well established in production. However even during the research and development phase the Project Director normally changes two or three times - whether the post is filled by serving officers or civil servants. The changes are brought about by promotion and by the policy of posting people for tours of duty in various jobs. They affect not only the Project Director, but also many of his staff as well, so that his team is constantly changing. Fresh ideas can make an important contribution to a project, but unless changes of staff take place at times which are phased into the needs of a project, they can cause serious disruption to its development. We recommend therefore that the appointments of Project Directors and their key staff should be made for a longer period related to the main stages of the project they are controlling. When it is desirable from career considerations to post the man to other work, more use should be made than at present of the machinery which exists for consultation between personnel and project management organisations on the best timing for such a move.

244. When a project goes into production the equipment developed for it by the specialist branches is often procured by the Ministry of Technology on separate contracts with the firms who have developed it. It is then loaned to the main contractor for embodiment in his aircraft or other system. This "embodiment loan" procedure is not limited to equipment specially developed for the project, but is also applied to many standard components which are used in a variety of projects. This practice has been widely criticised to us by the industry, chiefly on the ground that delivery of the equipment is often late, or that when delivered it does not work properly, although it has been accepted by the Ministry of Technology. This disorganises the main contractor's production and can cause him to deliver the whole system late.

245. The Ministry of Technology have informed us that they have modified their instructions on this subject within the last year or two and that broadly speaking the contractor is made responsible for procuring as much subsidiary equipment as possible. It is supplied on embodiment loan terms only

(a) where it is necessary for the Department to control the design, standardisation and interchangeability of the article and there is no other way of achieving this;

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(b) where the demand exceeds the supply and it is necessary to control the distribution between competing demands;

(c) where items cost more than £25 in production and there appears to be a significant cost advantage to be derived from centralised production.

The Ministry of Technology recognise the desirability of keeping embodiment loan equipment to the minimum in order to make incentive contracts more effective. If a contractor's ability to satisfy the terms of an incentive contract depends on the timely delivery of articles furnished by the Ministry of Technology, their later arrival or failure to function correctly when received give him a ready excuse for any shortcomings on his own part.

246. We welcome the efforts which the Ministry of Technology are making to stimulate efficiency by the use of incentive contracts and by attempting to set out clearly-worded criteria in order to limit the amount of embodiment loan equipment. However we have some reservations about the third criterion (c) for handling equipment under the embodiment loan procedure. We believe that there may be some justification for the industry's view that it is interpreted rather freely and that decisions are sometimes affected by other considerations than significant cost advantage. If the latter is not defined any more precisely than that we doubt whether the cost saving is always large enough to outweigh the extra administrative cost of handling equipment in this way.

247. We appreciate the cost advantages of standardisation and bulk purchasing. The Government have announced in a White Paper* their intention of seeking these advantages throughout the whole field of Public purchasing, and we believe that they should do so for defence procurement as for any other, where it offers genuine economies. However the opportunities for such economies in the type of products we are considering are inevitably diminishing as the equipment becomes more and more specialised.

248. The Ministry of Technology's present policy is consistent with our view that completion of a contract on time and within the estimated cost will be encouraged by the greater use of incentive contracts. If they are to be effective however, these contracts should contain as few loopholes as possible. The furnishing of equipment on embodiment loan terms inevitably creates such loopholes, and it should therefore be kept to the minimum. We endorse the criteria laid down by the Ministry for such equipment, but we recommend that the third should be improved by placing the onus upon the Ministry of Technology to demonstrate that there is "a significant cost advantage" after contingent costs have been taken into account, before they designate a component or other piece of equipment under this criterion.

THE EFFECT OF ACCOUNTABILITY TO PARLIAMENT ON PROJECT MANAGEMENT BY THE MINISTRY OF TECHNOLOGY

249. There has been criticism from the industry of the Ministry of Technology's slowness in pricing contracts. It is often contrasted with the speed with which we have been told these processes are accomplished commercially. It is natural for the aircraft industry to compare its two types of customer, but the financial environments in which the Government and Industry work are quite different.

250. A commercial firm uses "risk" capital subscribed by its shareholders, who judge its efficiency by the profit it earns for them from its work. Funds raised and appropriated by Parliament for Defence supply have nothing in common with risk capital; nor is a Department's efficiency in using them measured in terms of anything akin to profit. Parliamentary processes appear to concentrate on satisfying Parliament that the funds it has voted for a particular purpose have been properly applied. It has set up machinery to scrutinise each Department's accounts on its behalf, and to report on them. Through its Public Accounts Committee it can call upon Departmental Accounting Officers to explain any apparent improprieties revealed by this scrutiny.

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*"Public Purchasing and Industrial Efficiency" - Cmnd. 3291, May 1967

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251. It follows that officers throughout the Department when taking decisions about expenditure must at all times consider not only whether they are getting value for money, but also whether they can demonstrate that they are and can adequately defend their Accounting Officer's position before Parliament. The decisions themselves and the reasons for them must be recorded more thoroughly than would be necessary in the commercial world. In these circumstances it is hardly surprising that to industrial eyes civil servants appear over-cautious in their purchasing. It is difficult for them to take action based on their own judgment without adequately documented supporting arguments, even though they may believe, and events may confirm that it would have been cheaper to do so. Events may show the opposite, or give no indication of the rightness of their actions and in either of these cases they may be vulnerable. The caution which this system inspires is inevitably intensified in the defence field by the absence of competition for much of the work placed with industry and by the recent criticism the Ministry of Technology have experienced because some of their suppliers have made excessive profits from their contracts. The agreement recently reached between the Confederation of British Industries and the Treasury on new terms and conditions for non-competitive contracts will, we hope, reduce the likelihood of a recurrence of such events. We hope that it will also help to speed up decision-making and the agreement of prices.

252. During our inquiry we have had to concern ourselves with the paradoxical situation that a process designed to ensure that public funds are spent wisely can lead to the Government's getting less value for money than they might otherwise have had and weaken the export prospects of some of the products. We stress throughout this report the importance of quantity in aircraft manufacture. The Ministry of Technology recognise this in their policy of bulk purchasing of certain pieces of equipment which we have quoted in paragraphs 247-249 above. But we have mentioned in Chapter 11 the caution with which the Ministries of Defence and Technology enter into production commitments for aircraft still under development, lest subsequent modifications generate a great deal of scrap. The same is of course true of guided weapons also. This caution over quantity is found not only in the ordering of complete aircraft but of many of the parts and in the authorisation of manufacture as well. In the commercial situation the profit motive generally provides an incentive to opt for the known economies of quantity: they have to be balanced against the risk of an unknown amount of scrap which with luck may not be large. Government Departments have much less freedom to do this. Accountability to Parliament tends to produce a more cautious attitude aimed at keeping scrap to a minimum, because waste is considered synonymous with scrap, but not with paying higher prices in order to save the risk of scrap.

253. Both the commercial purchaser and the Ministry of Technology have to take such risks. They both must rely upon their judgment in dealing with the uncertainties they encounter. But officials, when taking decisions in these circumstances, are subject to the constraints we have enumerated and it is inevitable that they will be more cautious than commercial purchasers.

254. We believe that this attitude is one of the factors affecting efficiency which our terms of reference have asked us to identify. However the remedy for it must lie with Parliament and the way it chooses to carry out its surveillance of public expenditure and it would not be appropriate for us to make any recommendations on that subject. We can only draw attention to the consequences of this surveillance as it is at present practised and hope that in future a broader interpretation will be placed on "value for public money" and that those responsible may reflect on what their real aims should be and whether they are in fact being achieved.

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255. We formed the view early in our enquiry that one of the most important aims of the aircraft industry should be to design for cheapness of manufacture. In the past the absence of strong competitive pressure and the high status of designers compared with production men produced a situation in which ease of manufacture received less attention than it should. It may be argued that a designer who is competent should not allow this to happen: he is not designing in a vacuum and his creations have to be produced and sold. However the design of a complex modern aircraft requires large teams composed of people of varying ability, knowledge and imagination. Just as a critical assessment of a manufacturing process by an observer trained in method study will often reveal worthwhile economies, so the conscious application of certain disciplines to the design of industrial products can stimulate "second thoughts" which may lead to savings on the shop floor.

256. These disciplines have come to be known as Value Engineering when they are applied during the design of a new product and as Value Analysis when they are directed at an existing one. Their aim is to analyse the function or service that is to be performed by a product to see how it can be obtained for the least cost. They owe their origin to the Second World War, when shortage of many traditional materials made it necessary to use substitutes which did the required job satisfactorily and were often cheaper. This experience was developed after the war in the United States into a system which would reveal cheaper alternatives - not merely for the materials but for the whole design of a product - by intent rather than by chance. American manufacturers were quick to exploit this systematic approach, and in the 1950's British firms began to follow suit. The first to do so were mainly mass-producers. This was to be expected: value engineering and analysis add to the overhead costs of production a sum which is often large compared with the saving in cost on each unit produced. The larger the production run the more easily this investment can be recovered. This may explain why, with a few exceptions, the aircraft industry, which is characterised by relatively small production quantities, did not make much use of these techniques until about 1963. When its members began to apply them they concentrated on value engineering, because unless the savings which could be made were recognised very early in the life of the project, they were unlikely to justify the extra cost of identifying them. Therefore we are mainly concerned in this chapter with value engineering and we shall use this term to embrace the use of the technique at any stage in the design and manufacture of an aircraft.

257. The Ministry of Technology and their predecessors, the Ministry of Aviation, have encouraged the use of value engineering by letting study contracts to enable companies to familiarise themselves with the discipline through practical experience.

258. We set up a Sub-Committee, under the chairmanship of Mr. F. T. Hinkley to study the application of value engineering in the aircraft industry. Owing to pressure of other work, Mr. Hinkley later relinquished the chairmanship to another of our members, Mr. L. R. Beesly. The other members of the Sub-Committee included experienced value engineers drawn from a cross-section of companies and from the Production Engineering Research Association, which has been active in spreading knowledge of the subject.

259. The importance now attached by the industry to designing for the most economical production was apparent from the evidence submitted to us by a number of the largest firms, some of which we summarised in Chapter 12. The Sub-Committee sought more detailed information from them and from several others about their use of value engineering.

260. The Sub-Committee found that most of the companies they questioned had adopted value engineering during the last five years. About half of them used it right through the company and the same proportion had their own internal training programme. The rest relied on Consultants specialising in the subject to train their staff. The people selected for training were usually qualified engineers drawn from the design, and to a lesser extent the production, departments. However the number trained is at present only about three per cent of the design or technical force of the firms concerned.

261. Not all the firms found it easy to quantify the savings achieved by value engineers, but the Sub-Committee concluded that wherever the activity has been determinedly organised and properly applied, it has produced a return of between five and ten times the cost of carrying it out. This clearly demonstrates the need for value engineering. The Sub-Committee believed that the British aircraft industry is ahead of industry generally, and the application of value engineering by the leading companies is comparable with the best practice in the United States. We recommend that

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value engineering should be practised by all companies in the aircraft industry and also by their suppliers through all stages of engineering from concept to development, manufacture and in-service operation. The earlier it is applied, of course, the better, so that re-design, re-development and re-tooling are kept to a minimum. It cannot be carried out in a haphazard manner; it is essentially a team effort involving carefully selected representatives from the main departments of a company who have been thoroughly trained in the basic value engineering techniques.

262. When they first adopt the techniques companies need a formal value engineering organisation to arrange training for all their staff who are in a position to influence cost. When sufficient people have been trained however it may be preferable to disband the formal organisation and to depend on the individuals to apply the discipline in the course of their normal work, supplementing this by ad hoc groups to look at particular problems as they arise.

263. The Sub-Committee found that the status of the value engineering organisation in a company, in particular the level to which it reported, seemed to influence the proportion of suggested changes which were accepted by designers. It was highest where the team had the advocacy of a director who could ensure that maximum use was made of its ideas. Value engineers need the support of a director or as a minimum a senior executive charged with seeing that full use is made of their work. Other departments may have to modify existing procedures if value engineering is to be used as effectively as possible, for example by providing information on the cost of particular jobs and processes. At present value engineers often find difficulty in obtaining this information which is basic to their task.

264. Although the larger companies will no doubt find it more economical in the long run to establish their own training capability, others may find it preferable to rely on external courses as is the present practice of half the firms surveyed by the Sub-Committee. Many courses are now available from industrial agencies and consultancies but we believe that universities and technical colleges should give more prominence to value engineering in their curricula than they do at present. Students should learn as soon as possible about the cost of materials and processes as well as their physical properties. A competent engineer requires a knowledge of both. We believe that the Engineering Industry Training Board can play a part through its grant schemes in encouraging educational institutions to set up more value engineering courses, and in stimulating industry to make use of them.

265. There is already considerable enthusiasm for value engineering in many companies, but we have given some thought to ways by which the Ministry of Technology could encourage them further by contractual action. Whether it is practicable to extend this beyond a stipulation that value engineering techniques shall be used, and acceptance of their cost as an overhead, is at present being explored by the Department. The incorporation of financial rewards raises difficult problems both of measurement and principle. Whatever is decided, we feel that those who are considering the question should keep clearly in mind the need to stimulate the use of value engineering and avoid anything which would hamper it.

/CHAPTER 19

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266. In Section III of this report we showed that Britain took a significantly longer time than the United States to develop and prove military and civil aircraft. Much of the difference lay in the length of flight testing programmes in the two countries.

267. There can be little argument that anything which can be done to shorten the time spent on flight testing will be beneficial to the aircraft concerned. It improves the competitive position of aircraft in the world market. It reduces the time span between the definition of a military requirement and its realisation, and hence the possibility of change in the role for which the aircraft was ordered. It will probably also reduce development costs, though this cannot be stated categorically, since extra manpower and facilities will almost certainly be required.

268. In this Chapter we examine the reasons why British projects take longer from first flight to certification and release for Service and suggest some measures to shorten the time required. We deal with civil projects first.

CIVIL AIRCRAFT

269. Flight trials of civil aircraft serve two purposes. The manufacturer's trials demonstrate the extent to which the performance and handling of the aircraft match the designers' expectations. Before the aircraft is granted a certificate of airworthiness it must satisfy a statutory body as to its safety in operation. In the United Kingdom this body is the Air Registration Board; in the United States it is the Federal Aviation Agency. Both assess the safety of the aircraft in similar ways. They monitor the manufacturer's trials during development and their own pilots also fly the aeroplane to assess its airworthiness. In addition, both authorities make an assessment of the functional reliability of the aircraft over a relatively short period of proving flights on typical operational routes.

270. The certification trials in both countries are closely interwoven with the manufacturer's test programme. There is no evidence that the ARB procedures prolong development flying to any greater extent than those of the FAA. Neither the Board nor the manufacturers believe that this is the cause of Britain's slower flight test programmes. The reason must be sought therefore in the way in which the manufacturer's trials are undertaken.

271. American manufacturers carry out more extensive testing of sub-systems and components, not only in the air - as exemplified by the high-lift devices for the Boeing 727, which were first tested in flight on a 707 wing - but more particularly on the ground.

272. During development trials of a new aircraft, American firms devote very intensive effort and resources to the task. Their aim is to get as much information as possible from each flying hour and to analyse it as fast as possible, so that there can be quick feedback of results to designers and to succeeding trials. In order to do this, they install more elaborate instrumentation in the test aircraft, devote more computer capacity to the task of data reduction and employ large numbers of flight test engineers and data analysts. These resources are used in shifts, often round the clock. Flying programmes also benefit from somewhat better and more dependable weather in many parts of the United States than they usually enjoy in this country.

273. By adopting the approach we have described, American firms are able to reduce the number of hours flown to a little more than half those for comparable British aircraft. Thus while the Trident required about 1,800 flying hours for flight development and certification, the Boeing 727, an aircraft very similar in size, in performance and aerodynamically, completed its flight testing in about 1,100 hours. In calendar time, because of the more intensive utilisation, the 727 required only nine months against the two years for the Trident. Although the latter made its first flight a year earlier than the 727, it actually entered airline service a month later.

274. The solution of this problem is simpler in theory than in practice. The British aircraft industry cannot readily recruit new staff with the necessary experience in flight data collection, processing and analysis. Even if it could do so, it could not offer them continuity of employment. New projects are undertaken at much longer intervals in Britain than in America. The workload of flight development staff already fluctuates considerably. In these circumstances the limit to which the peaks of activity can be intensified and shortened in duration is quickly reached. Shift working can save a lot of time on a project but it demands extra staff, and adds to the problem

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already mentioned of maintaining the workload between projects. The additional staff would have to be backed by better facilities for data reduction and analysis. These could be more easily justified economically if they were to be used continually on three shifts. All these arguments point to the use of fewer and better equipped flight test centres.

MILITARY AIRCRAFT

275. Flight test programmes for military aircraft also serve a double purpose. The aim of the manufacturer's trials is the same as for a civil aircraft, though the flight performance which he has to explore is usually much more demanding. But the acceptance trials to determine whether the aircraft meets the Operational Requirement and is fit for service are much more extensive in scope than those of the Air Registration Board. This is because they have a quite different purpose. The Air Registration Board is concerned only with safety in operation and is independent of both manufacturer and customer. The Aeroplane and Armament Experimental Establishment, which conducts acceptance trials for military aircraft, assesses not only safety but the whole spectrum of performance and operational suitability of the system. Furthermore it is part of the Ministry of Technology, and is therefore contractually involved in the project which it has to assess. This means that it may have to advise the Department how well a contractor has complied with the specification given him. At the same time, its freedom to reject, unlike that of the ARB, is constrained by the cost of design changes to the Department.

276. For these reasons, acceptance trials are less closely integrated with the manufacturer's experimental flight testing than those of the ARB. Contractors complain that this articulation of the trials unnecessarily inflates the cost of the project and delays its entry into service. We have considered carefully whether there is scope for combining more closely manufacturers' and acceptance trials. Although there are obvious dangers in pursuing this policy too far, we believe there is further scope for co-ordination in this respect.

277. We have in any case no evidence that A & AEE trials prolong programmes unduly in comparison with the procedures adopted by other countries. The United States Air Force and Navy, and the French Ministry of Defence all have establishments which operate in a very similar way to A & AEE. They conduct the same sort of trials for the same purpose, though each country emphasises certain aspects more than the others do. A & AEE tend to concentrate on the assessment of qualitative characteristics which are difficult to specify numerically. They rely on the contractor's test results for most quantitative data, which they verify by spot checks. The emphasis which the American Services place on quantitative specifications linked to performance incentives leads them to place much greater weight on numerical results. This apparently greater precision does not necessarily save time. Agreement on the numerical expression of certain performance characteristics may be preceded by lengthy debate. The greater planning which it calls for is undoubtedly an advantage when the flight programme is under way, but we have no evidence that generally acceptance trials are to blame for the longer flight test programmes of British projects.

278. We believe it is much more likely that the reasons why Britain takes longer to prove military projects are the same as we have noted for civil aircraft. In addition to mustering more extensive support for their trials, American manufacturers, encouraged by the Government in its military contracts, spend much more effort on reliability testing of components and sub-systems on the ground before flight trials begin. This has been rewarded by a reduction in the number of flying hours wasted because of equipment failure. It may well be an area to which we could profitably devote more attention.

279. One fact which has emerged quite clearly from our study of this question is that the answer does not lie simply in using a greater number of test aircraft. These will only yield benefit if they are supported by adequate airfield, flight test, servicing and data processing facilities. Thus where funds are limited, they would be more effectively spent on these than on extra aircraft.

280. We have no doubt that British projects would benefit from a reduction in the time taken by flight trials. The promise of earlier delivery would make them more competitive and attract more orders than at present.

281. The greatest reduction can be achieved by ensuring that as little flying time as possible is wasted because of unserviceability, and by flying more intensively than at present.

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282. Flight test missions frequently have to be abandoned because equipment in the aircraft is unserviceable. More comprehensive ground testing of components and systems - to establish their reliability before they have to perform in the air - would cut down such failures. It is almost always much cheaper to prove equipment on the ground than in flight, even though it may demand more manpower, simulators and test equipment. The cost of them must be weighed against the savings in flying hours, and in the prompter introduction of modifications into production aircraft which they make possible. At the same time extra effort devoted to testing should not be allowed to delay the start of flight trials. The testing must be done in parallel with design and construction of the development aircraft so that time is definitely saved, not merely taken from one stage of the project and added on to another. Otherwise the benefits of earlier certification will all too easily fail to materialise.

283. It is the time needed for the reduction and analysis of data obtained during test flights which presents the main obstacle to more intensive flying. More flying hours per month could be achieved, and test programmes completed more quickly, if the supporting staff and equipment on which they depend were better, larger and more effective. At present they are dispersed among a large number of airfields. The main airframe groups operate several for this purpose, the smaller airframe companies each have one and so do some equipment manufacturers. The increase in staff and capital equipment which would be needed for more rapid analysis of data, where necessary on a shift basis twenty-four hours a day, cannot be justified in this situation because at none of the airfields would they be employed continuously enough.

284. It seems to us that the answer must lie in concentrating the analysis and interpretation of flight test data in a few, better equipped centres. There might for example be one for each major group, and one for the smaller firms who would all stand to benefit from a pooling of their resources. It may be more difficult to concentrate flying activities in the same way, although every effort should be made to do so. Where this was not feasible, data-links would be needed to connect the flight test staff with the analysts, and in some cases the analysts with the design offices. We recognise that this is less convenient than having all three organisations based at the same place, but we believe that its disadvantages would be more than compensated by speedy availability of data from better equipped, more fully staffed data handling centres of the kind we propose.

285. Trials at the A&AEE would be less amenable to this approach, firstly because they are already concentrated at a single airfield and secondly because the emphasis they lay on qualitative as well as quantitative assessment means that the trials staff are not so dependent on data processing for the information on which their judgments are based. They already work outside normal hours when particularly difficult problems threaten to delay the completion of a trials programme. In view of the desirability of keeping to a minimum the time taken by flight testing, we recommend that the Ministry of Technology should consider instituting some form of shift working on a routine, not just an emergency basis at the Establishment and to take all other practicable steps to speed up the trials it undertakes.

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286. The direct manhours required for production depend firstly on the techniques employed - which determine whether the processes of manufacture are labour-intensive or capital-intensive - and secondly on the effectiveness with which labour is used, i.e. the proportion of time spent on productive work, the rate of working and the extent to which the learning effect is exploited. Both the choice of techniques and the effective use of labour are clearly management responsibilities. The successful introduction of some of the improvements which we believe to be necessary will require close consultation with the trade unions concerned, but it is management who must take the initiative in seeking greater efficiency. We consider techniques first.

TECHNIQUES

287. In an earlier chapter we showed that after allowing for differences in the scale of production there was still a significant disparity in output per manhour between the British and American industries. We estimated that in Britain between 25 per cent and 50 per cent more manhours were used to accomplish a given task. It is tempting to suppose that American companies can produce aircraft with less direct labour than British firms because they are more mechanised. The fact that several of the largest American aircraft companies have for every employee about three times the value of fixed capital assets found in British firms would seem to confirm this surmise. But when we visited some of these American factories we found, paradoxically, that generally methods of manufacture differed little from those used in this country. It is true that in one factory we saw a line of large machines newly installed for automatic rivetting of wing panels, but we also saw many aircraft being assembled by traditional hand rivetting. There were numerous machine tools of advanced design, but they were familiar types which are used by many British aircraft firms who, in proportion to their smaller turnover, employ them in similar quantities. We found it difficult to reconcile the balance sheet evidence of a much greater investment per man with our observation of American manufacturing techniques, but we believe we have identified some reasons for the apparent contradiction. First, much of the investment has been in real property. Modern well-designed factories laid out for easy handling of modern aircraft can make an important contribution to productivity, though less obviously than capital plant. Secondly the larger scale of production in the United States justifies the more lavish provision of small multi-purpose power tools of advanced design, so that operatives do not have to wait to use a shared tool. This no doubt reduces the time required for many jobs and promotes higher productivity. Thirdly capital assets tend to be more expensive in the United States; building work and large machine tools can cost half as much again as they do in the United Kingdom. The much higher level of capital investment undoubtedly contributes to the American industry's greater productivity, perhaps more in the manufacture of components than in the airframe factories, where its effect is smaller than might be inferred merely from a study of balance sheet figures. Finally, the ratio of fixed capital to turnover is not so very different in the two countries. A high ratio of fixed capital to labour employed could be produced simply by greater efficiency in the use of labour as a result of better labour practices, shop floor management and production control.

288. The way in which an aircraft is manufactured, and even the way in which it is designed, necessitate compromises between the technically desirable and the economically practicable. What is economically practicable depends largely on the quantity in which the aircraft will be produced. Where there is a choice of technical solution, the manufacturing method chosen is strongly influenced by the plant available and the balance of fixed and variable costs associated with a particular process. The manufacture of large structural members provides a good illustration. To provide increased strength and rigidity designers have called for large spar members, for example, to be made from a single piece of metal, much of which has to be removed to conform to the design pattern chosen to give the required strength at minimum weight. This machining is a very lengthy and costly process and wastes a considerable amount of high quality and expensive material. The desired result could be achieved in a very much shorter time by forging the member close to the required form and thus reducing considerably the amount of machining. The forging can be produced in a fraction of the time required to mill the part from solid; its variable costs are proportionately low. But the capital cost of a large forging press and the dies required for each job are many times those for the most elaborate milling machine. These fixed costs have to be amortised over the production run. Where quantities are small the burden of fixed cost and of setting-up cost outweighs the advantages of shorter operating time and makes the forging quite uncompetitive with the much more laborious machining operation.

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289. This example involves two fundamentally different methods of manufacture, but similar considerations apply when companies wish to improve a particular method, such as machining, by the adoption of new equipment. The various types of control of machine tools which have appeared in the last ten years or so have had a revolutionary effect on the time taken to remove metal. This saving has only been achieved by means of complex equipment costing many times more than the older and slower machines it supersedes. Although the saving in time required for each job can be quite remarkable, the lower labour cost can easily be offset by increased depreciation costs unless the equipment is kept fully utilised. The higher labour rates paid by American companies make labour-saving capital equipment correspondingly more attractive to them than to British companies.

290. Numerically controlled machine tools nevertheless offer many benefits to the British aircraft industry. They are versatile. They speed up manufacturing processes, reduce scrap, and demand less skill from the operative. The industry, recognising that its efficiency, like that of any other, depends on its being adequately equipped with up-to-date manufacturing facilities and on its taking advantage of any improved types of equipment that become available, has not been slow to seize the opportunities offered by the new machine tools when it has been economic to do so. The capital expenditure policy of firms in the industry is directed basically towards enabling them to reach the highest possible standards of efficiency. The application of this policy however is subject to certain conditions. One of them is the need to obtain an adequate return on new capital investment. In practice this means that an annual return of something like 20 per cent must appear possible before a decision is taken in favour of it. Since this return will be forthcoming only if the assets enjoy a high level of utilisation, they are not likely to be acquired unless there is a strong possibility of achieving this high utilisation during the early years of their life. The availability of cash also affects the decision. Demands for capital often exceed the cash available for investment and the various schemes have consequently to be arranged in some order of priority. Investment decisions are also affected by the taxation system, including Government grants, depreciation and wear and tear allowances.

291. These are general conditions that affect all business. But in the aircraft industry there are some additional factors which arise from the close dependence of the firms on Government policy. In particular, lack of confidence about the Government's policy in regard to projects for new aircraft discourages firms from undertaking capital expenditure on new buildings and plant which might increase productivity. Firms can reasonably be expected to be able to assess commercial risks, but the uncertainties of doing business with the Government introduce risks of a different order. For instance, Government orders for initial batches of aircraft are said to be seldom large enough to justify the purchase of elaborate and expensive special purpose plant, and firms are therefore left to speculate about whether there will be sufficiently large "follow up" orders to make their investment in such equipment worthwhile. It is true that they are faced with much the same problem in producing civil aircraft, but in that case the risks are market risks of a kind which firms can be expected to assume and which are unlikely to be affected by incalculable changes in official policy.

292. When they purchase equipment for the use of the armed services, the Ministry of Technology have a duty to obtain them in the most economical way. In principle they expect the companies to whom they offer contracts to be equipped to undertake the work. However they are not unware of or indifferent to the problems which it presents, particularly when a contract demands advanced and expensive capital equipment for which no other application is foreseen. For example, the cost of special jigs and tooling required exclusively for work covered by a Government contract is charged direct to the contract. If the plant can be regarded as "tools of the trade" however, the contractor is expected to provide it from his own resources. This may mean that a firm is obliged to incur capital expenditure where it cannot see how the whole of the cost is going to be recovered. Also because the Government allow depreciation to be charged to overheads only at the rates allowed for taxation purposes, the assets must be amortised over a period of years which far exceeds that covered by Government contracts at the time they are purchased. Exceptionally where equipment is of a very special nature, though not required exclusively for one contract, the Ministry of Technology may accept an accelerated rate of depreciation in the contractor's overheads; in other cases they sometimes extend Capital Clause Cover for the equipment. This indemnifies the contractor against a loss where the written down value of the equipment at the end of the contract is higher than the price he can obtain for it. These measures do something to mitigate the problem, but they by no means eliminate it.

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293. It is reasonable for firms in the private sector working mainly for a competitive market to base their decisions on investment by reference to the annual return that is expected and for this judgment to be influenced by such factors as their view of the future course of demand, the impact of the tax system, and the availability of cash resources in relation to competing claims on them. It is less rational to allow these factors to determine the investment decisions of firms much of whose current production and future planning is determined by Government decisions, especially when these are in turn closely dependent upon changing political and strategic requirements.

294. It is easier to enumerate the adverse consequences for efficiency of this situation than to suggest a practical remedy. Investment decisions are one of the most important functions of the Board of a company. If the Government begin to play an active role in these decisions as well as providing massive launching aid for civil projects and the entire finance for domestic military projects, it could be argued that the industry might just as well be nationalised.

295. The alternative is a more stable environment. If this could be achieved over periods comparable to the long development cycle of an aircraft, it would be reasonable to expect the industry to take its own investment decisions and ultimately to raise its own finance on a normal commercial basis. We dealt at some length with the subject of stability in Chapter 15.

296. Attention is being given to these problems. Many of them were taken into account during the recent negotiations between the Government and industry in general which led to agreement on a new profit formula for use in non-competitive contracts. The Ministry of Technology are currently reviewing their policy on the provision of Capital Assistance to contractors. In conjunction with the Confederation of British Industries they are also examining the whole question of overheads, including such matters as the treatment of depreciation.

297. Because of these examinations and because decisions in this field must inevitably be influenced by political considerations, we have limited ourselves to pointing out the obstacles which exist at present to greater capital investment and hence to greater productivity.

EFFECTIVE USE OF LABOUR

298. From what has been said in the first part of this Chapter it will be apparent that the advantages of using improved labour-saving equipment are likely to be more apparent in shorter lead-times than in substantially cheaper production. Even in America, where labour is much more costly, we did not find that mechanisation and automation constitute the main reason for greater productivity.

299. The most economic method of carrying out certain operations is bound to differ from country to country according to the price and availability of labour and capital. Whatever method is chosen, however, output will vary according to the effectiveness with which labour is used. This is largely a matter for management and the trade unions. We were doubtful whether the aircraft industry was getting the maximum output from its human resources. In part this was because of the imperfections of production control which form the subject of the next Chapter. But we also believed that the industry's wage structure, although designed to stimulate output, had lost some of its power to do so and at the same time inhibited flexibility and encouraged wage drift.

300. We engaged P.A. Management Consultants to make a short study of the value of the wage structure in four airframe factories, whether it presented any impediments to flexibility in the use of labour, and if so what changes might facilitate improvements in labour utilisation. We have also been able to compare their findings with the result of a similar study they undertook in several aero-engine factories.

301. The Consultants confined their attention to the productive labour force. Between a quarter and a half of it in the airframe factories, and all of it in the engine factories, was employed in three types of large shop on which the study was therefore concentrated viz., machine shop, manufacture of detail parts, and structural (including final) assembly. They contained a cross-section of all grades of skill, though skilled workers predominated - they formed at least a half, and in one factory 85 per cent of the productive labour force.

302. In common with the aircraft industry in general in this country, but in contrast to the American industry, a high proportion of the labour was paid on some type of incentive bonus scheme. This proportion averaged 60 per cent, but was as high as 85 per cent in one factory studied.

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303. The payment schemes varied in detail from factory to factory, but all shared the same basic features. The employee's pay is normally made up of a basic rate and a piecework supplement agreed nationally between the Confederation of Shipbuilding and Engineering Unions and the Engineering Employers' Federation. To this combined hourly rate is added an incentive bonus which is calculated as a percentage of the basic element of the hourly rate according to the amount of time saved against a target for each job. In addition there may be individual payments for merit. We were particularly interested in the effectiveness of the incentive bonus element (the only one directly geared to output per manhour) as a stimulus to higher productivity.

304. Target times in the aircraft industry are negotiated between rate-fixers and operatives. It is difficult to establish accurate times for some jobs, particularly those involving assembly, because successive types of aircraft differ so much that previous experience is a poor guide. Furthermore negotiated times, which should allow an average level of bonus to an operative of average ability, depend partly on the strength of the negotiating position of the rate-fixer and the operative with whom he agrees them. Because of the marked affect of "learning" in aircraft manufacture, the target time will be influenced by the experience already accumulated before it is negotiated.

305. In a large workshop it is to be expected that operatives' speed of working will be distributed normally about the average performance. Therefore if rate-fixed times accurately reflect the average pace of working, bonus earnings will also show a normal distribution. The Consultants said that they had found this to be so in other industries they had studied. They had also found that the normal width of the spread of earnings either side of the mean was about 25 per cent - less where the time taken for a job depended largely on the speed of a machine or process.

306. In the four aircraft factories they studied, machine shops approximated fairly closely to this pattern. The structural assembly shops, on the other hand, revealed a wide spread of bonus with a plateau rather than a peak defining the average. The detail shops, as might be expected, lay between these two extremes.

307. The Consultants interpreted these results as indicating imprecision in the rate-fixed times. The machine shop was considered to be the easiest in which to fix accurate times and it conformed more closely to the expected pattern than the detail and assembly shops. The companies acknowledged that it was harder to fix rates for the latter, largely because of the dearth of reliable records on up-to-date production techniques.

308. The analysis suggested that employees were exploiting "loose" target times to control their earnings, and therefore that the incentive bonus schemes were not achieving their aim of stimulating maximum output. The Consultants held that the bonus offered was not geared highly enough to output to provide sufficient stimulus. Although this is probably true there would be difficulties in increasing the gearing of existing schemes because to do so would magnify errors in rate-fixing.

309. In Britain the target time for each job is fixed at a fairly early stage in the production run and cannot be re-negotiated unless there is a change in production method. The effect of learning enables the operative to earn his bonus progressively more easily, but if he restricts his earnings, as has been suggested, he obstructs a very important source of improved efficiency. This is no doubt one of the reasons why the learning effect has been found to tail off rather early in British production.

310. Thus far we have spoken only of the benefits to the operative. The employer in return for the higher hourly cost of labour gets more output per hour (so his labour cost per unit produced may well be lower), more intensive use of capital facilities, and more rapid turnover of funds tied up in production.

311. The Swedish company Saab have sought to preserve these advantages by negotiating with the Union a scheme whereby for assembly work the target time is geared to a learning curve. Thus if he is to "keep level" the operative must take advantage of the increased facility which comes from learning to accomplish the job in a progressively shorter time. However, this facility comes naturally and does not prevent his exerting extra effort to earn a higher bonus. Whether he does so or not, the better utilisation of capital facilities is assured. There are special temporary allowances to compensate personnel who are moved to a job which is already established. We do not pretend that the Saab system is perfect, but we believe that if some way

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could be found of taking account of learning in British incentive schemes it would make a valuable contribution to productivity. Several British aircraft contractors have new payment systems under consideration for workers on incentive bonus schemes and these recognise a learning period. These proposals all accept a termination of the learning effect at a finite number of units, and are not geared directly to an assumed learning curve as at Saab.

312. Our Consultants felt that other aspects of the wage structure militated against the effective use of labour. In particular they believed that the traditional relationship between rates for "skilled" and "semi-skilled" workers was, for many of the jobs in the aircraft industry, no longer appropriate. Changes in some manufacturing techniques, such as the introduction of numerically controlled machine tools, substitution of plastics for sheet metal in many applications, and the use of more accurate jigs, have reduced the skill required. They concluded that the aircraft industry would benefit from a new structure based on job evaluation techniques for all types of work. The structure could be based on either more highly geared incentive schemes, or on flat rate payment for work where it seemed more appropriate.

313. The conclusions the Consultants reachsd in the short time available to them confirm our impression that typical payment schemes in use in the aircraft industry are not providing an adequate incentive to higher output. Furthermore variations in the accuracy of target times hamper flexibility, since operatives are reluctant to move from a generously rated job to one with a more exacting target.

314. The undoubted difficulty of establishing accurate times for assembly work in particular, combined with the steepness of the early part of the learning curve raises the question of whether payment by results is still the best way to stimulate high output. The American industry prefers flat hourly rates, with increments given for skill and/or length of service. This alternative has much to commend it. It satisfies the desire for stable earnings. It is much simpler to operate, saves a great deal of bookkeeping and allows more flexibility in the deployment of labour. Its drawback, from the point of view of management, is that it places a greater load on supervision. Many British companies, including some in the aircraft industry, are experimenting with flat rate payments in place of incentive schemes, but it is as yet too early to assess the effect of this change on output, which can only be judged over a period of years.

315. Under a flat rate system of payment, the responsibility for maintaining, and where possible increasing, output must rest on the shop floor supervision, the foremen and charge-hands. In American firms they are responsible for ensuring that the economies afforded by learning are achieved; the jobs under their control must be completed with progressively reduced manpower. The American manufacturers whom we visited laid great stress on this fact, but it must be recognised that their managements can cut down manpower for each job more easily because the greater mobility of American labour produces a higher rate of wastage in their labour force and hence makes it more flexible; by contrast British workers are less mobile. They also emphasised the importance of selecting as supervisors men of suitable calibre and personality, and of training them and paying them for their responsibility. These requirements apply no less when flat rates are paid in Britain, where the status and authority of supervisors have been eroded by many factors. If supervisors did not have to concern themselves with bonus considerations as a result of their allocation of jobs, we believe they might, with suitable training where necessary, cope with the new responsibilities placed on them. However we believe also that the industrial climate in Britain would make the supervisors' task much more difficult than it is in the United States.

316. Flat rate systems have undoubted attractions, as does the Swedish approach of gearing bonus to the learning effect. We have not gathered sufficient evidence to enable us to assess the relative merits of applying each of them in this country. The short study which was undertaken for us however does, we think, indicate that changes in the wage structure of the aircraft industry could make a worthwhile contribution to productivity. The details of such a revised structure can only be worked out by consultation between management and unions in an individual company. But its aim should be to find the type of payment system which is most appropriate to each class of work in the industry. Whatever type of wage structure is adopted, ways should be sought of enabling both the operative and the company to benefit from the increasing facility which comes naturally as a result of learning, and the whole structure should be designed to encourage the skills which the industry most needs. At the same time managements should improve the quality and authority of shop floor supervisors by more careful selection and training.

/CHAPTER 21

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317. During their manufacture aircraft undergo rigorous inspection to ensure that, except where concessions have been expressly authorised, they conform in every detail to the designers' drawings, specifications and test schedules. This check is undertaken primarily by works inspectors employed by the manufacturer. The standards they observe have to be approved by public bodies which also verify that they are maintained. The body concerned with civil aircraft is the Air Registration Board (ARB). Standards of inspection for military aircraft, and for other similar work carried out on Government contracts, are supervised by the Inspection Division of the Ministry of Technology.

318. This organisation has wider responsibilities than the ARB. It is concerned with a much greater range and value of equipment - which comprises not only aircraft, but their supporting ground equipment, as well as guided weapons, atomic weapons, ground radar and telecommunications, and marine craft, to name only the larger categories. As part of the Ministry of Technology, the Inspection Division is a party to the Ministry's contracts. Before a manufacturer can obtain payment for the goods he delivers on these contracts, a Ministry of Technology inspector must accept them on behalf of the Department. In doing so, he endorses the quality of the goods supplied. In a similar way an inspector must "accept" development aircraft manufactured on a Ministry of Technology contract before they may be used for test flying. This procedure is adopted because the Government bears the risk of, and any costs of repair and replacement arising from, a mishap to the aircraft. Before each one flies, the resident Ministry inspector must certify from the records of its inspection during manufacture that it is fit to do so. The two Directorates - Aeronautical (AID) and Electrical (EID) - which make up the Division, maintain laboratories and test-houses which provide a service not only to the Department, but to the ARB and industry as well. Because they are conveniently situated at all major contractors' works, AID inspectors carry out many additional duties on behalf of other branches of the Ministry. The ARB does not accept goods on behalf of civil customers, who often second one or two representatives to the manufacturer while the aircraft they have ordered are under construction to ensure that they conform to the contract specification. Nor does the Board certify that development aircraft are fit for flight. It leaves this to the manufacturer, who takes out insurance against the risks which the Government bear for military projects. It can be argued that the Board's task as a whole has been eased by the standards and traditions established by AID and EID, though the extent of the Board's dependence on them can, of course, only be judged subjectively and we have encountered widely differing assessments of it from those who gave evidence to us. Nevertheless it seems fair to say that without the two Inspectorates, the Board would have been a somewhat larger organisation. In stressing the more limited field of the Board's responsibilities, we must however not forget that they include some for which the Military counterpart is found elsewhere than in the Ministry of Technology's Inspectorates, notably the establishment of airworthinsss standards, the flight testing of aircraft for certification (described in Chapter 19) and the supervision of maintenance work carried out by airlines.

319. Thus direct comparison of the ARB and the Ministry's inspection organisation is difficult. Nevertheless when allowance has been made for all the differences between them, the inspection of Government contracts appears to require many more staff than are necessary for civil manufacture. The ARB employs about 360 people, of whom the technical staff constitute almost exactly half. The Inspection Division of the Ministry of Technology is more than ten times larger, and about three-quarters of its staff are technical. They include 1,500 industrial workers - skilled, unskilled and apprentices - who have no counterpart in the ARB. The Board's technical staff similarly include flight test personnel and surveyors (inspectors) stationed at maintenance bases, whose military opposite numbers do not form part of the Ministry of Technology's Inspectorates.

320. The manufacturer also finds it necessary to use more works inspectors for military than for civil work; in airframe companies there is commonly one inspector for about five productive workers employed on military contracts, whereas on civil aircraft the ratio is one for seven or eight.

321. There is no evidence that the ARB system produces results which are in any way inferior to those achieved by AID. We have therefore considered whether there might be advantages in adopting for Government contracts a procedure similar to that used by the Board. If the aircraft responsibilities of the Ministry of Technology's Inspectorates could be reduced to something like those of the ARB, worthwhile economies in manpower - amounting to many hundreds of people - should be possible in the Department. A reduction in the number of works inspectors might also be

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possible. These economies would be reflected in lower costs. To achieve them three major procedural changes would be necessary. Firstly the goods delivered would have to be supported by a manufacturer's guarantee that they complied with specification. A further guarantee covering defects arising in service might also be desirable. The American Government buy most of their equipment on these terms; so do civil customers. The price is increased accordingly, the premium depending on how comprehensive a guarantee is required. It has been put to us that the responsibility which the Minister of Technology bears for the quality of equipment he procures for the Services is more satisfactorily discharged by direct inspection than by recourse to the contractor, with its attendant difficulties of proving liability, after trouble has occurred. However there is no evidence that direct supervision influences the incidence of defects, one way or the other. The greater complexity of military aircraft makes fair comparison difficult, but civil aircraft certainly do not have more teething troubles than military when they enter service.

322. Somewhat similar considerations govern insurance against the risks of prototype flying and here a second procedural change would be necessary. The Government bear many risks which in the private sector would be covered by insurance because it is cheaper over the whole public domain to stand the relatively small number of claims which do arise than to cover every possibility by insurance. We do not doubt the wisdom of this principle for the generality of risks. If however to protect themselves they find it necessary to establish the procedures we have described for approving military development aircraft before each flight or series of flights, we question whether this is really more economical than insuring commercially.

323. Finally some other ways would have to be found of carrying out the peripheral duties at present undertaken by AID.

324. The objections which arise from these consequences of change toward the ARB procedure have considerable force. Nevertheless the present inspection procedures appear to us very costly in terms of Ministry of Technology staff and add to the contractor's cost of production. It may be difficult to quantify all the financial advantages and disadvantages of both approaches, but it should be possible to predict the extra cost which insurance premiums and guarantees would add to the price of military aircraft. It should also be possible to calculate how much they could save in works inspection cost and in AID staff, when allowance has been made for carrying out by other means the subsidiary liaison duties at present undertaken by the latter.

325. We recommend that the Ministry of Technology should carry out a broad investigation to quantify the order of magnitude of the potential savings. If these appear worthwhile a more detailed exercise would clearly be necessary. The Committee under the chairmanship of Colonel G. W. Raby which is currently examining inspection procedures in the Ministries of Defence and Technology could well have views on the problem.

/CHAPTER 22

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326. We come now to an activity which offers great scope for improving the output, efficiency and prosperity of the aircraft industry - the planning and control of manufacture.

327. Efficiency on the production floor will only be achieved if there is a constant flow of materials or components to the operative; this, however, must not he achieved by substantial overstocking. If an operative is held up he will either take longer at his job or hook "waiting time"; either will create not only a reduction in his earnings but also in his output. Under these conditions the operative will use his ingenuity to spread his earnings evenly taking advantage of any inaccuracy in rate fixing.

328. The responsibility for maintaining a steady and uninterrupted flow of work for each operative lies with the Production Planning and Control Staff. At an early stage of our enquiry we came to the view that this was an important area where there was scope for improvement so we set up a Working Party composed of people with considerable production experience from BAC, Hawker Siddeley and Rolls-Royce to advise us where the improvements were most needed. Their report is reproduced at Annex E.

329. Subsequently our visit to the United States confirmed our view. We found much greater attention paid there to detailed planning and control of production than has been customary in the past in the United Kingdom. The results of it are evident in the strict adherence to delivery schedule on which the American manufacturers justly pride themselves, in the high and effective utilisation of their production labour and in the much smaller amount of working capital they employ in relation to their sales turnover. In a sample of five of the largest American aircraft and aero-engine companies, capital employed in stocks and work in progress represented on average 2.6 months' sales, compared with 4.6 months' sales for five similar British firms. While the profits for the American and British companies are similar if expressed as a percentage of sales, the profits expressed as a percentage of the total capital employed were 15.3 per cent and 8.8 per cent for the American and British companies respectively. If the British firms could have reduced their inventory to the American proportion, their return on capital would have been increased from 8.8 per cent to 12.5 per cent.

330. The better-managed British companies are well aware of the desirability of such a reduction. It is clear from evidence they submitted to us that within the constraints imposed by very small batches, they are trying hard to ensure a smoother flow of work through their production shops in order to keep their delivery dates and make fuller and more economic use of their resources.

331. Our Working Party found a close similarity in the way the three largest groups in the industry were tackling the problem. They concluded that further improvements could be effected on four aspects of it, namely people, organisation, systems design and data processing. These are stated in the order of priority in which the Working Party considered they should be tackled but they considered them all to be closely related. They also drew to our attention other factors outside the control of Production Planning which can have a marked impact on efficient production. Some of these we have mentioned elsewhere in our report.

332. Until very recently production has been regarded with some disdain by graduate engineers entering industry and by the senior management of many companies. They have seen production control as a routine clerical activity demanding dogged application and the processing of large quantities of paper rather than as a task requiring bright new ideas. Consequently graduate engineers entering industry in this country have shown a marked preference for jobs in the design and development departments.

333. Managements have done little to dispel this impression, perhaps because they tend to be composed of people who have risen mainly through the design and development departments. It is an irrational attitude, however, because production is the end result from which the profits are made and investment in R & D recovered. The Americans have been quick to see these problems but British firms have been slower to improve the status of production management staff, and hence have experienced a shortage of people of the right calibre.

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334. The College of Aeronautics and the newer universities, notably those which were formerly Colleges of Advanced Technology, have shown an awareness of the industry's need of production specialists. They are trying to cater for it, particularly through sandwich courses, which are one of the main sources of qualified production staff. We consider industry's demand on the technical institutions must increase. At the same time leaders of the industry, if they are to recruit staff of the right quality, must make it clear that they regard production as equal in importance to design and development and that it offers good opportunities of promotion.

335. As a result of the merging of many autonomous companies into a few large groups there have been opportunities for improved efficiency in the organisation of production control by specialisation or by more efficient loading at the units. In some cases this has been achieved by concentrating a particular process or manufacture of a particular component for a number of projects at one factory. Examples of such rationalisation are mentioned in Chapter 12.

336. Dividing up the production of a project between a number of factories, each of which has its own production control organisation, presents new problems of co-ordination. A central production control office for each project is essential if the various parts from these dispersed production lines are to come together at the right time and in the right place for final assembly. At the same time the establishment of a two-tier control system complicates communication and paper work. The Working Party expressed the view that data processing equipment would be needed to handle this work. We have commented in more detail on this aspect in paragraphs 342ff. However, we are certain that this type of organisation does require careful, detailed and efficient planning carried out by a high calibre of staff if the benefits of grouping factories are not to be lost.

337. A number of instances have been drawn to our attention where systems require further development. Examples included determination of batch sizes, lead times for manufacture and methods of progressing. There is a temptation to regard lead times as something immutable, which they are not. Our Working Party analysed the lead time for production of a special purpose bolt, indicating how the manufacturing time could be varied from a standard of eight weeks to one day depending on the urgency with which the part was required. This example can be related to our comments in paragraph 329 about the capital cost of stocks and indicates one of a number of fertile fields for investigation. While clearly the bolt can only be completed in one day by giving it priority over all other parts, it should be possible by careful planning to achieve a compromise and reduce stocks of parts without affecting the efficiency of the shop floor.

338. The lead times of work done in the manufacturer's own workshops are generally within his control. If components are late, he and only he has the means to correct the situation. The bought-out and sub-contracted items - which include raw materials - present a more difficult problem which we have described in paragraph 124. At its heart lies the fact that lead times are long because Britain does not sell enough aircraft to provide an incentive to high performance, and that Britain does not sell enough aircraft because among other reasons her lead times are too long.

339. We believe that although their aeronautical businsss may not form a large part of their output, many of these suppliers value their participation in the British aircraft industry very highly. They may not appreciate how important an effect their own contribution (which may be physically quite small) can have on the delivery of the finished aircraft, nor how greatly earlier and more reliable delivery of their products could improve the prosperity of the industry as a whole, bringing it and them larger and more valuable orders. A wider use of vendor rating by the major airframe and engine manufacturers would help to secure better performance from the suppliers to whom aircraft business matters. Where it proves unsuccessful, the aircraft manufacturers in their own interest must look abroad for alternatives.

340. Finally our Working Party took the view that automatic data processing was indispensable in attaining significant improvements in production control at all levels, because the combination of the large volume of parts, the frequency of change due to modifications and the need for prompt information have made it increasingly difficult to plan and control production efficiently using only manual effort.

341. They emphasised that at this stage it is not possible to show specific economic savings which have resulted from using computers for this task, but drew to our attention the probable advantages which would occur from the more powerful computers now available and new techniques such as the use of random access storage devices and data collection equipment.

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342. In the United States, while the majority of companies are using Advanced Data Processing Techniques, we saw manual systems in operation in two factories. One of them was producing advanced military aircraft in many variants at a high rate, and although it used a computer for planning, monitored achievement against this plan manually. The other was manufacturing a civil aircraft at a lower rate more characteristic of British production lines. Both, so far as we could judge, maintained a more effective control over the flow of work than is usually achieved in this country, and the latter ruled out A. D. P. as uneconomic for such a low volume of output. Hence, while we agree with the advantages of Data Processing we do not regard it as impossible to improve existing systems without the use of Computers.

343. A. D. P. enables more precise assessments to be made of complex loading situations, and will digest a greater amount of control information than is possible using only human effort, but we regard it as desirable rather than essential to the improvement of production control. The ingenuity applied to systems work, which is an important but separate preparation for data processing, will automatically find better ways of handling the data, whether or not this is subsequently programmed for a computer. Similarly only human ingenuity can ensure that the quality of the input information - on which the accuracy of the output depends - is the highest possible.

344. We consider that whether or not a company decide to use a computer will depend to a large extent on the magnitude and complexity of their projects linked with the quantity to be produced.

345. Production planning and control is the area where the British aircraft industry has in the past lagged furthest behind the American. We recommend that managements devote urgent attention to the quality of the staff they assign to this task, and to the systems used to carry it out. Both need to be improved to ensure

(a) a smoother flow of work and hence more efficient use of shop floor labour;

(b) a well-balanced load so that delivery dates can be met;

(c) that lead times are shortened so that earlier delivery is possible and that stock and work in progress absorb less working capital.

/SECTION VI

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SECTION VI - SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

In summarising our conclusinns and recommendatione we have concentrated on the areas where improvements are needed. At the eame time we realise that in the four years since evidence wae taken by the Plowden Committee the industry has taken many steps to overcome the probleme it faces. We have described eome of them in Chapter 12. We have aleo noted throughout our report a number of measnres which the Ministry of Technology have instituted to improve their methods of working and their collaboration with the induetry, and we believe that the very existence of our Committee and the queetions we have asked have added some impetus to both the Government's and the induetry's eearch for better ways of doing things.

A eummary of our principal conclusions and recommendations, which are unanimous, is given below.

PRODUCTIVITY

(1) Measured by value added for each of its employees, the British aircraft industry'e productivity is approximstely one third that of the American industry. It is not inferior to thst of the French industry, its other major competitor.

(paragraphs 40, 45)

(2) By far the most important factor contributing to this "productivity gap" is the small scale of airframe production in Europe. If allowance is made for the difference in prodnction quantities, the ratio of productivity in the United Statee and Britain is found by several independent methods to be between 1.2 to 1 and 1.5 to 1. This is the true rstio of the "effectiveness" of manpower in the two countriee.

(psragraphs 56, 63, 72, 84)

(3) Because Britieh productivity ie lower than American, the British industry forfeits the cost advantage which it should gain from its lower wages and salaries, and competing aircraft cost about the same in both countriee.

(paragraph 40)

(4) Engines are made in relatively greater numbere than airframes and the manhours required to produce them sre about the same in both countriee. The British industry therefore gains some of the advantage of its lower wage rates, though it still suffers from smaller total production rune than are usual in the United States.

(paragraphs 56, 84)

TIMESCALE

(5) British projects generally take longer than American, though less time than French from the beginning of design to final certificstion. The extra time needed is not spread uniformly over the various stages of development. For s number of civil projects the average time from the beginning of design to first flight was in fact less for the Britieh than for the American aircraft. However this advantage was more than offset by the much longer time needed from first flight to certificstion, and by the greater length of British production cycles.

(paragraphs 117-8, 124)

EFFECT OF QUANTITY

(6) The most important step towards improving the industry's productivity would be to make each type of aircraft in larger quantities. Because of the way in which the "learning effect" operstes a comparatively emall increase in the quantity in which an aircraft is produced can yield a more than proportional increase in its competitiveness. If Britain had the courage to plan the production of its aircraft on a larger scale it would be able to quote pricee so much lower than those of its competitors thal it should have no difficulty in capturing a large share of the market.

(paragraphs 158, 171-2)

/CHOICE

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CHOICE OF PROJECTS

(Civil)

(7) As a general principle a new project should be started only when firm prospects of sales are large enough to make its development economic and its selling price competitive. This principle would seem too obvious to require enunciation had it not been so frequently disregarded in the past.

(paragraph 161)

(8) The world market for most types of civil aircraft is expanding but Britain needs to choose new projects which will not only be in wide demand, but which can exploit her strongest areas of technical expertise, the advantage of her lower wages and salaries, and the goodwill earned by earlier aircraft, and for which she has adequate resources to ensure delivery at the right time.

(paragraphs 163-166)

(9) The ratio of R & D cost to the total production cost is a much more important criterion for the selection of a project than their absolute values. The magnitude of R & D cost need not of itself deter Britain from undertaking advanced aircraft projects, provided that the cost estimates and sales forecasts can be relied upon.

(paragraph 169)

(10) Specifications should not be tailored too narrowly to the requirements of a single customer. Sales to the Corporations, while of great value to the industry, do not appear to boost foreign sales.

(paragraphs 176-7)

(Military)

(11) The criteria for choosing civil projects are also important in the selection of military projects, though they will inevitably be modified by other considerations. However the pressure on defence funds makes it very important that the Services should do everything they can to ensure that their equipment has maximum export potential.

(paragraphs 178, 180)

(12) Better project definition and estimating procedures should encourage the Services to place their production orders earlier. Such a display of confidence would help to stimulate foreign orders and the larger total production would reduce domestic prices.

(paragraph 182)

COLLABORATIVE PROJECTS

(13) The attractions of collaboration with other countries and its potential benefits have tended to obscure its disadvantages. These stem mainly from the length of time taken to reach decisions at Government level, and from the fact that considerations of national interest and balancing financial contributions do not necessarily result in the most efficient division of work. It may be that collaboration can only be really effectively achieved if the initiative in seeking opportunities and negotiating partnerships is taken by industry with the support of the Ministry of Technology. The Ministry of Technology should review critically their experience of collaborative projects and seek ways of implementing the policy which are more compatible with efficiency and speedy execution of the work.

(paragraphs 186-192)

THE NEED FOR STABILITY

(14) The stability of workload which is essential to the industry's forward planning is unlikely to arise except by chance from the present practice of taking decisions piecemeal on individual projects. In the absence of a clear long term policy for the industry it cannot be expected that the best decisions will be taken or adequate stability achieved. In Chapter 15 we have described a possible approach to the problem of achieving greater stability, which would lead to the appointment of a high-level group from the Government and the industry to work out a plan.

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(15) Stability is impossible without reliable cost estimates. The procedures recommended by the Ministry of Aviation's Steering Group on Development Cost Estimating should be generally adopted, particularly its proposals for more thorough project definition studies.

(paragraphs 211-2)

(16) Operational Requirements and Technical Specifications should be defined comprehensively by the time full development begins. Ths past practice of filling in the details as work proceeded, and even as lats as the Final Conference, is not conducive to economy or efficiency.

(paragraphs 214-5, 218)

(17) In the context of a fixed overall defence budget, it is no longer practicable to define the ideal weapon and then estimate what it will cost. It is necessary to start with a figure which can be afforded and then work out what it will buy. Before they authorise full development of a project the Government should determine, with the advice of the main contractors involved, a firm and realistic cost limit which they are prepared to pay for its development and production. The aim should be to contain all increases in cost within this by adjusting the specification and/or the production quantity. The limit should be revised only on account of inflation, or if some unavoidable grave setback is encountsred during development.

(paragraphs 222-4)

(18) In order to reduce the risk of a grave setback, future projects should not rely on the simultaneous development of too many novel techniques. More use should be made of proven techniques and components, either developed in advance with general applications in mind ("building blocks") or adapted from previous projects. When the system has been proven in this way, more advanced replacements for older parts of it should be developed where justifiable.

(paragraph 224)

(19) Early in their consultations on a new project ths Ministries of Defence, Technology and the main contractor should define the key decisions which will have to be taken and the dates by which they must be taken. Failure to reach decision by the due dates, and its consequences for the timing and cost of the work should be reported to the three parties at a senior level.

(paragraph 228)

PROJECT MANAGEMENT

(20) The amalgamation of tschnical and financial responsibilities, and of technical and administrative staff in the new Ministry of Technology Project Directorates is proving effective and should be extended whsre practicable to other areas of the Ministry's aviation work. Project Directors should also be made responsible for the production of at least the initial batches delivered to the Services.

(paragraphs 236-8, 242)

(21) The term of office of individual Project Directors is often shorter than is in the best interest of the project. When career considerations make necessary the posting of a Project Director to other work, more regard should be paid to timing this event so that it occurs at a convenient and logical point in the development programme.

(paragraph 243)

CONTRACTS

(22) We support the present policy of the Ministry of Technology of employing Incentive Contracts wherever possible. To avoid weakening the discipline of such contracts the Ministry should make the main contractor rssponsible for as much of the system as they can. They should continue to apply strict criteria in designating equipment to be provided on "Embodiment Loan" terms, and they should demonstrate that there is a significant cost advantags in production before they designate something according to that criterion alone.

(paragraphs 246, 248)

(23) The type of scrutiny which Parliament has recently applied to Government expenditure breeds a very cautious attitude on the part of officials which militates against greater

/efficiency.

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efficiency. A wider interpretation of what constitutes "value for public money" is needed if projects are not to be slowed down and made more costly than necessary.

(paragraphs 252-4)

VALUE ENGINEERING

(24) Companies should increase their efforts to inculcate a greater consciousness of production cost in all parts of their organisation. More staff should be trained in the techniques of Value Engineering and a senior executive should be responsible for ensuring that cost saving proposals are exploited to the full. The Ministry of Technology should encourage the use of Value Engineering when placing its contracts.

(paragraphs 261-5)

FLIGHT TESTING

(25) The calendar time occupied by flight trials should be reduced. More thorough ground testing of systems and components is needed before flight, and more intensive data analysis. The industry should concentrate the staff and equipment required for the latter task at fewer places and work shifts round the clock. The Ministry of Technology should ensure that effort at A & AEE is adequate to match more intensive work by contractors, and to enable acceptance trials to be completed in a shorter time than hitherto.

(paragraphs 280-5)

CAPITAL INVESTMENT

(26) Lack of stability particularly in the work placed on the industry by the Government, coupled with certain contract pricing rules, deters the industry from investing as much as it might in modern capital equipment. We hope that our recommendation (14) and reviews of contract pricing rules currently in progress will lead to ways of reducing this discouragement.

(paragraphs 291-7)

WAGE STRUCTURE

(27) The present wage structure of the industry does not provide the intended incentive to operatives, nor does it exploit the beneficial effects of learning as fully as it might. Management and unions should jointly seek a more appropriate wage structure for the aircraft industry with these aims in view.

(paragraphs 308-9, 313, 316)

QUALITY

(28) The industry should consider making wider use of formal schemes to promote quality-consciousness, presented in a way which will arouse enthusiasm in its employees and avoid conflicting with the aims of payment by results.

(paragraph 104)

INSPECTION

(29) The Ministry of Technology should investigate the possibility of an inspection procedure on the lines of that practised by the Air Registration Board.

(paragraph 325)

PRODUCTION CONTROL

(30) The area where the British aircraft industry has in the past lagged furthest behind the American is Production Control. It needs to improve both the quality of its staff and the systems it employs for this task in order to ensure

(a) a smoother flow of work and hence more efficient use of shop floor labour;

(b) a well-balanced load so that delivery dates can be met;

/(c)

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(c) that lead times are shortened so that earlier delivery is possible and that stock and work in progress absorb less capital. If they had kept the value of their inventory as low in relation to their turnover as American firms do, five of the largest British companies could have increased the average return on their capital from 8.8 per cent to 12.5 per cent.

(paragraphs 329, 345)

ST. JOHN ELSTUB (Chairman)
G. C. ALLEN
L. R. BEESLY
HANDEL DAVIES
W. G. DOWNEY
J. L. HILTON
F. T. HINKLEY
R. L. LICKLEY
D. A. LOVELOCK
F. W. PAGE
J. H. N. THOMPSON

H. J. BLANKS (Secretary)

/Annex A

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List of those from whom Written Evidence was received

The Aircraft Industry

The Society of British Aerospace Companies Ltd.

Beagle Aircraft Ltd.
British Aircraft Corporation (Operating) Ltd.
British Hovercraft Corporation Ltd.
Dowty Rotol Ltd.
Dunlop Co. Ltd. (Aviation Division)
Elliott Automation Ltd.
English Electric Co. Ltd.
Ferranti Ltd.
General Electric Co. Ltd.
Handley Page Ltd.
Hawker Siddeley Aviation Ltd.
H. M. Hobson Ltd.
Lucas Gas Turbine Equipment Ltd.
Marconi Co. Ltd.
Louis Newmark Ltd.
Normalair-Garrett Ltd.
Plessey Co. Ltd.,
Rolls-Royce Ltd.
Rotax Ltd.
Short Brothers and Harland Ltd.
Smiths Industries Ltd., Aviation Division
Sperry Gyroscope Division, Sperry Rand Ltd.
Standard Telephones and Cables Ltd.
Ultra Electronics Ltd.
Westland Helicopters Ltd.

Other Bodies in the United Kingdom

The Air Registration Board
British European Airways Corporation
Production Engineering Research Association
The Royal Aeronautical Society

Consultants

Associated Industrial Consultants Ltd.
P.A. Management Consultants Ltd.

Individual

Mr. R. Worcester

Government Departments

Ministry of Defence
Ministry of Technology

United States of America

McDonnell-Douglas Corporation
North American Rockwell Corporation

/Annex B

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(I) List of those who gave Oral Evidence to the Committee

The Air Registration Board

Mr. T. D. Guilbert
Mr. W. Tye

British Aircraft Corporation (Operating) Ltd.

Mr. J. Cattenach
Mr. R. Heeks
Mr. D. J. Lambert
Dr. A. E. Russell

British European Airways Corporation

Mr. J. Garton
Mr. I. Grant-Murray
Mr. R. C. Morgan
Mr. K. G. Wilkinson

Hawker Siddeley Aviation Ltd.

Mr. J. C. D. Cotes
Mr. G. A. Whitehead

The Royal Aeronautical Society

Mr. A. D. Baxter
Sir George Gardner
Dr. H. H. Gardner

Individual

Mr. R. Worcester

Consultants

Associated Industrial Consultants Ltd.

Mr. D. N. D. Heenan
Mr. M. M. Murray
Mr. W. S. Paxton

P. A. Management Consultants Ltd.

Mr. V. F. Thompson
Mr. E. W. Woodhams

Government Departments

Ministry of Defence (10 representatives)
Ministry of Technology (15 representatives)

(II) Organisations visited by the Committee in the United Kingdom

British Aircraft Corporation (Operating) Ltd.
Hawker Siddeley Aviation Ltd.
Imperial Metal Industries Ltd.
Rolls-Royce Ltd.

/(III)

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(III) Organisations visited by the Committee in other Countries

Sweden

Royal Swedish Air Force Board
Saab A. B.
Svenska Flygmotor A. B.

United States of America

The Boeing Company
McDonnell-Douglas Corporation
North American Rockwell Corporation
Rand Corporation
An airline

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SOURCES OF THE INDUSTRY'S INCOME

£ million

Year	Government			Home Civil	Export	Total
	Research and Development	Procurement	(a) Assistance			
	(b)					(b)
1960	90	182	3	29	109	413
1861	106	208	11	50	111	486
1882	107	214	12	25	89	447
1963	108	210	12	29	88	447
1864	108	215	12	76	87	498
1985	116	216	20	80	131	563
1966	104	201	33	42	199	579
1967	88	212	52	59	159	570
1988(c)	85	215	70	80	195	845

NOTE: Recent years revised in the light of more detailed analysis of Mintech expenditure

(a) Assistance to the development, proving and production of transport aircraft.

(b) Excludes terminal payments, not representing actual work done on cancelled projects.

(c) Provisional.

/Annex D

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Annex D

Ref: Chapter 6

STUDY OF COMPARATIVE PRODUCTIVITY

REPORT BY ASSOCIATED INDUSTRIAL CONSULTANTS LTD.

Consultants:

D. N. D. Heenan

M. M. Murray

W. S. Paxton

February 1969

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1. INTRODUCTION

Our work on the study of Comparative Productivity for the Committee started in the first week of October, 1967; the terms of reference for the study are shown in Appendix A.

Initial contacts with Ministry and contractor sources of data were completed by mid-November. The contractors included:-

British Aircraft Corporation (Operating) Ltd.
Hawker Siddeley Aviation Ltd.
Rolls-Royce Ltd.
Westland Helicopters Ltd.

The contractors have provided data on a strictly confidential basis, for use only in respect of this work for the Committee. To ensure that all firms concerned are satisfied that any data in this report is suitably anonymous, we have first agreed the presentation of data with these firms.

The draft of the report has also been discussed with the following individual Committee members:-

Mr. L. R. Beesly
Mr. W. G. Downey
Mr. F. T. Hinkley
Mr. R. L. Lickley
Mr. F. W. Page
Mr. H. J. Blanks, the Secretary to the Committee

and also with the officials of the following branches of the Ministry of Technology:-

APG Plans
PTC/An
Air C1

These discussions have been extremely helpful in allowing us to benefit from specialist comment in certain areas. We believe that the resultant final report is now a more useful document to the Committee, although the discussions have not altered the main findings arising from the examination of the available data.

We have dealt with both engine and airframe data in this report. A summary of our findings is given in Section 2. Our conclusions and observations on areas where further investigation may prove worthwhile are given in Section 3. Detailed lists are contained in the Appendices.

2. SUMMARY

2.1 Major Conclusions

In essence, the terms of reference for this study required us to compare data on the time and cost of U.K. aerospace projects with data embodied in reports of the Rand Corporation on U.S. projects. Our conclusions are qualified, partly by limitations in the data available on U.K. projects and partly by limitations in applicability of the Rand analysis to the U.K. sample.

Subject to these qualifications our major conclusions are as follows:-

(a) for airframes, the mean input of manhours on U.K. projects is higher than that predicted by the Rand formulae. The most significant differences are:-

Engineering manhours:	mean U.K. actual manhours are 1.26 times U.S. prediction.
Tooling manhours:	1.67 times U.S. prediction
Total manufacturing manhours:	1.38 times U.S. prediction.

/(b)

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(b) it is often suggested thaf U. S. productivity is superior to U. K. productivity by a factor of between 2. 5 and 3. 0. This ratio is based on global economic comparisons which are not weighted to allow for the effects of different average production runs.

We have based our calculations on actual U. K. airframe production runs, which are significantly shorter than in the U. S. Allowing for this our findings are broadly compatible with the global ratio.

(c) for aircraft turbine engines our analysie indicates that both for development and procurement effort are broadly in line with the levels predicted by the Rand formulae. This conclusion is subject to a number of major qualifications and must be treated with reserve.

(d) even after allowing for differences in scale of production, it appears that U. K. productivity is relatively low in airframe manufacture and tooling. We consider that substantial bensfits might be obtained in these areas by examining and subsequently improving manpower utilisation and performance. We therefore suggest that direct observation techniques should be used to evaluate variations in these important parameters of productivity, between the U. S. and U. K. industries and between the various manufacturing locations in the U. K.

2. 2 Basis of Comparison

The results of our study are given as ratios, for each of the categories covered by the Rand formulae. These ratios compare the actual expenditure in manhours or cost in U. K., with the manhours or cost predicted by the Rand formulae for ths same project in U. S.

It is important to note the following major qualifications as to the basis of this study. These are expanded in Section 6. 3 of this report.

(a) The Rand data was designed for use in long range planning studiee and not for international comparisons of productivity.

(b) The Rand Cost Estimating Relationships were derived only from military aircraft and engines produced in significant quantities; they may not be apposite to U. K. aircraft induetry.

(c) The steps in the "state of the art" are different in the U. S. to U. K.

(d) The interpretation of the definitions and the impossibility in some categories of aligning the U. K. data to conform to the Rand definitions, all limit the validity of the comparisons. All the U. K. data used includes the effect of all modifications.

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2.3 Airframes

2.3.1 Summary Results Unedited Sample

$$\text{Ratio} = \frac{\text{Actual Hours or Cost}}{\text{Calculated Hours or Cost}}$$

Cost Estimating Category	Lowest Ratio	Highest Ratio	Mean	Approx. Productivity (Mean)	No. of Airframes in Sample		
					Military	Civil	Total
Total Engineering Hours	0.9	2.1	1.26	n.a.	2	6	8
Initial Engineering Hours	0.8	1.3	1.05	n.a.	1	1	2
Total Engineering Cost	0.2	0.7	0.38	0.97	2	7	9
Development Support Cost	0.2	0.8	0.37	0.94	1	7	8
Flight Test Cost	0.2	1.2	0.50	1.27	2	5	7
Tooling Hours	0.9	3.1	1.67	n.a.	3	4	7
Tooling Cost	0.4	1.4	0.70	1.78	3	6	9
Total Manufacturing Labour Hours	0.9	2.0	1.38	n.a.	6	9	15
Total Manufacturing Labour Cost including Quality Control	0.4	0.9	0.60	1.52	8	9	15
Final Aircraft, Manufacturing Labour Hours	1.1	4.0	1.66	n.a.	6	9	15
Manufacturing Material Cost	0.5	3.0	1.44	n.a.	4	7	11

For cost only categories the approximate productivity =

$$\text{mean ratio} \times \frac{\text{U.S. direct rate per hour}}{\text{U.K. direct rate per hour}}$$

/2.3.1

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2.3.1 cont'd Summary of Results - Airframes Edited Sample

$$\text{Ratio} = \frac{\text{Actual Hours or Cost}}{\text{Calculated Hours or Cost}}$$

Cost Estimating Category	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	Approx. Prod. (Mean)	No. of Airframes in Sample		
						Military	Civil	Total
Total Engineering Hours	0.9	1.3	1.14	0.19	n.a.	2	5	7
Total Engineering Cost	0.2	0.4	0.35	0.08	0.89	2	6	8
Development Support Cost	0.2	0.5	0.30	0.10	0.75	1	6	7
Flight Test Cost	0.2	0.6	0.39	0.13	0.99	1	5	6
Tooling Hours	0.9	1.8	1.43	0.31	n.a.	2	4	6
Tooling Cost	0.4	0.8	0.61	0.14	1.54	2	6	8
Total Manufacturing Labour Hours	0.9	1.6	1.25	0.20	n.a.	8	5	11
Total Manufacturing Labour Cost including Quality Control	0.4	0.7	0.54	0.08	1.32	6	5	11
Final Aircraft, Manufacturing Labour Hours	1.1	1.9	1.36	0.25	n.a.	8	5	11
Manufacturing Material Cost	0.5	0.7	0.61	0.09	n.a.	4	1	5

For cost only categories the approximate productivity ratio =

$$\text{mean ratio} \times \frac{\text{U.S. direct rate per hour}}{\text{U.K. direct rate per hour}}$$

2.3.2 Comments

Detailed comments on each category of the results will be found in Section 5 of this report. They are summarised below.

(a) Engineering Manhours. The ratio of input of manhours for Engineering is 1.26 and 1.14 for the unedited and edited results respectively.

In the U.K. sample the cost in hours expended on major modifications has been included whereas it was excluded from the U.S. data. Consequently the strictly comparative result must be nearer parity.

(b) Development Support. The ratio of Development Support is 0.30 and 0.37 for the unedited and edited results respectively. However, the Rand definition includes the development costs incurred by suppliers of materials and components. The U.K. data does not include these costs. This difference lowers the ratio results and gives an unduly favourable impression of U.K. costs in this area; thus they can only serve as a general guide.

/(c)

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(c) Flight Test. Ths ratio of Flight Test Cost is 0.50 and 0.39 for the unedited and edited results respectively. The results from this relationship are very erratic as can be seen from the spread which may be caused by differences in testing procedures and the inclusion of civil aircraft.

(d) Tooling. The ratio of Tooling hours is 1.67 and 1.43 respectively for the unedited and edited results. This ratio is already higher than any of the others. It would be even greater if it had been possible to include within the U.K. data the hours incurred in Production Planning. According to the Rand definition these hours are included under Tooling. It is possible that the number of modifications relative to the number of aircraft produced in U.K. may significantly affect the tooling hours. Further the Rand cost estimating relationship includes the rate of production as one of its parameters and this may be insensitive to the relatively low production rates which are characteristic of U.K. projects.

(e) Manufacturing Labour Hours. The ratio of manufacturing Labour Hours is 1.38 and 1.25 for all airframes produced, 1.66 and 1.36 for the final airframe, respectively for the unedited and edited results. The difference between the total airframe ratio and the ratio of the last airframes appears to indicate that the learning curve in the U.K. flattens out relatively early whereas, according to Rand, the U.S. curves continue on a 75% unit curve. This indication is not true for all U.K. airframes in our sample. In fact five of the airframes show a small reduction between their respective total airframe ratio and their last airframe ratio.

The unedited results reflect the effect of customer requirements for civil aircraft and therefore are not comparable with the Rand formulae.

(f) Manufacturing Material Cost. The ratio of the cost of manufacturing material is 1.44 and 0.61 respectively for the unedited and edited results. The accuracy of the available data under this heading is insufficient to give even a rough guide as to relative cost.

(g) Civil/Military Airframes. Without commenting on individual results and excluding the obvious effects of customer requirements on civil airframes, the ratios do not indicate any significant difference in productivity between civil and military airframes.

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2.4 Turbine Engines

2.4.1 Summary Results - Unedited Sample

$$\text{Ratio} = \frac{\text{Actual Cost or Price}}{\text{Calculated Cost or Price}}$$

Approximate productivity ratio =

$$\frac{\text{Actual Cost or Price}}{\text{Calculated Cost}} \times \frac{\text{U.S. Direct Rate per hour}}{\text{U.K. Direct Rate per hour}}$$

Cost Estimating Category	Lowest Ratio	Highest Ratio	Mean	No. of engines or marks in sampls
Cost Basis				
Development Cost	0.18	0.59	0.42	12
Procurement Cost	0.21	0.96	0.44	23
Approx. Productivity Basis				
Development Effort	0.46	1.49	1.05	12
Procurement Effort	0.50	2.42	1.12	23

Edited Sample

Cost Estimating Category	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	No. of engines or marks in sample
Cost Basis					
Development Cost	0.20	0.58	0.41	0.12	9
Procurement Cost	0.21	0.64	0.38	0.14	18
Approx. Productivity Basis					
Development Effort	0.50	1.47	1.03	0.31	9
Procurement Effort	0.50	1.64	0.96	0.37	18

2.4.2 Comments

(a) Development Cost. The ratio of the cost of development is 0.42 to 0.41 and for productivity 1.05 to 1.03 respectively for unedited and edited results. As these relationships and the U.K. actual data were all expressed in terms of prices charged including profit the ratios can only be used as a guide, indicating that there is little difference in productivity between the U.K. and U.S.

(b) Procurement Cost. The ratio of cost of procurement is 0.44 to 0.38 and for productivity 1.12 to 0.96 respectively for the unedited and edited results. As for Development these ratios can only serve as a guide indicating parity of productivity. The cost estimating relationship for turbine engines with afterburners gave results lower than the same engines without afterburners at the reduced thrust. In consequence the afterburner equations were not used.

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3. OBSERVATIONS AND RECOMMENDATIONS

3.1 The Findings

The overall findings summarised above are not seriously at variance with the generally accepted ratio of manufacturing productivity, when allowance is made for the apparent productivity differences between U.S. and U.K. which are due solely to the volume of production. It will be interesting to see if our findings are confirmed by the outcome of the current examination by the Rand Corporation of two civil and two military projects in U.S. and U.K. We understand the results of this exercise will be available to the Committee.

However, our findings do indicate that, for airframes, there is a considerable difference in the output per manhour between U.S. and U.K. operatives in the areas of manufacturing labour and tooling. As demonstrated in the Section 4, these differences exist even when compensation is made for the variation in average length of production run between U.S. and U.K. projects. In other areas, for example Flight Test, Development Support and Engineering, the differences are less significant:-

Figures from table in Section 2

Area of Cost	Mean ratio of productivity	
	UNEDITED	EDITED
Engineering Hours	1.26	1.14
Development Support Cost	0.94	0.75
Flight Test Cost	1.27	0.99
Tooling Hours	1.67	1.43
Manufacturing Labour all aircraft hours	1.36	1.25
Manufacturing, final aircraft, hours	1.66	1.36

For engines, as for Development Support and Flight Test above, the analysis results indicate an approximate parity between U.S. and U.K. productivity.

In Section 5 and in the Summary we indicate the major qualifications which surround our findings. These are to be expected in conclusions from statistical data; they are unavoidable in a study of this type, where two separate national samples are compared. In addition these results of necessity can only give relative values; no absolute results can be achieved owing to the form of data comparison.

However, the findings do permit the identification of areas in which there are major differences in productivity: they do not evaluate the differences precisely nor do they show any of the causes of such differences.

3.2 Recommendations

There are, clearly, many possible causes of low productivity in the aerospace industries. They include small production runs, low rates of manufacture and high levels of modification. While these factors are widely recognised as important they are by their nature extremely difficult to quantify or to correct.

However, within the limits imposed by these factors, it may well be possible to obtain significant improvements in productivity by raising the utilisation and effectiveness of the labour force. In particular, this study indicates that the major differences between U.K. & U.S. productivity are in the areas of airframe manufacture and tooling.

We suggest that the optimum way to corroborate and evaluate these differences is by direct observation. This technique is especially applicable in the two areas of manufacturing labour and tooling although it is also used as a tool in many other areas of

/manual

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manual and intellectual activity. In many fields, managements now recognise that despite long and intimste knowledge of operations, controlled observation will reveal new facts and promote more objective assessment.

Direct observation by experienced staff using activity sampling techniques can provide data relatively quickly and within limits of error which are known and controlled. The technique allows for environmental conditions and, apart from providing the baais for deduction of causes of particular productivity levels, it may also identify these causes directly.

We therefore suggest that the Committee should institute an examination in the airframe industries in U. S. and U. K., which would employ direct observation of manufscturing labour and tooling activities in order to:-

obtain a measure of the performance of individusl workers when fully utilised (i. e. the rate of working of the operative compared with the standsrd established by the BSI effort rating scale)

obtain a measure of the level of utilisation of individual workers (i. e. the time spent on effective work compared with the total time available for effective work)

examine differences in environmental conditions including differences in plant, equipment and metbods.

Hence this examination would provide a direct and objective measure of two major determinants of labour productivity - utilisation and working pace. This direct assessment bas not, to our knowledge, previously been made for the U. K. industry as a whole. It would certainly provide a more rsliable and more revealing picture of overall performance tban any global, statistical or other indirect assessment. It would enable productivity differences to be quantified in precise and unambiguous terms: between individual units of the U. K. industry and between tbe total industries of the U. K. and U. S.

We consider thst sucb an investigation would provide both industry and Government Departments with a relatively exact measure of differences in productivity and of the reasons for them; these bave been lacking from the many indirect methods of comparisons previously employed.

If this direct evaluation of U. K. /U. S. operations confirmed that significant differences in productivity did exist, then the Committee's investigations could proceed with examinations which would identify the causes of these differences and the most appropriate corrective measures.

3. 3 Summary of Proposal

Our analysis indicates that U. K. productivity is relatively low in airframe manufacture and tooling even after allowing for the effects of different average production runs. We therefore suggest tbat the Committee should institute a study which would examine these two areas in deptb. This study would be in two stages:

Stage 1 would employ direct observation, to measure individual performance and utilisation

Stage 2 would use the results of Stage 1 to determine the causes of productivity differences and the necessary corrective measures.

We appreciate that there could well be difficulties in securing tbe agreement of U. S. airframe contractors to this type of investigstion. In some areas consideration of security would also restrict the choice of observers and observed. In this event substantial benefits could still be obtained by limiting the exercise to U. K. contractors. The study would then be used to evaluate the sxtent and causes of differences in labour utilisation and performance between the various manufacturing locations in the U. K.

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4. PRODUCTIVITY COMPARISONS

In our analysis we have calculated the ratio of the actual U.K. hours or costs to those predicted by the Rand formulae for the same parametere. The qualifications and reservationes on these results are listed in Section 5 of this report. If they are ignored then the ratios (particularly for manhours) are a direct measure of the relativs input of manhours between the U.K. and the U.S. for the same airframe, production numbere, and production rate. The relative input of manhours is one measure of productivity.

It muet be stressed tbat this ie not the same measure as the normal comparative meaeure of international productivity, which is a global measure. In the global method the output in terme of cost, price, weight or numbers produced is divided by tbe number or total cost of the employees. An international comparison of output per man on the global metbod therefore includes the effect of differing: products, rates of production, volume, extent of own manufacture etc.

Hence we have two indices of productivity:-

(a) relative input of manhours for specified output and (b) value of output per man. It is poesible to modify the global index to allow for the length of the production runs.

To assess the effect of production volums one can take the average runs for military and civil aircraft, as given in tbe Plowden Report, and assume that both the U.S. and U.K. achieve a 75% unit learning curve. Then, for manufacturing labour, due only to the longer production runs the U.S. output per man in airframe manufacture will sppear to be approximatly 1.6 times the U.K. for military airframes and approximately 1.9 times for civil airframes. (For details of this calculation and similar ones for tbe otber categoriee of the cost estimating relationshipe, see Appendix G).

The global measures of relative productivity between the U.S. and U.K. are normally quoted as 2.5 to 3.0 times. If these are divided by the apparent increase due to the larger production quantitiee, then an index will be obtained wbicb is an approximate measure of the relative productivity levels for the same products and quantities. For manufacturing labour the corresponding modified index will be 1.3 to 1.9 times U.S. to U.K.

Our analysis of manufacturing labour gives a cumulative index of 1.25 to 1.38 for the same production quantities, which is of tbe same order as the modified global index quoted above. (Similar reeults for the other cost categories are sbown in Appendix G). Our reeulte therefore correspond broadly to the global differences in manufacturing productivity of 2.5 to 3.0, including the effects of the longer production runs in the U.S.

We do not have details of the production runs of turbine engines in the U.S. and are therefore unable to calculate the corresponding effect of production quantities.

5. AVAILABLE BRITISH DATA

Ministry of Technology

We investigated the type of data maintained or recorded within branches of the Ministry of Technology. This did not reveal any actual data in a form suitable for comparison with Rand formulae. This situation was confirmed when specific requests were made to various branches to supply data in the form required (see Appendix E). In response to these requests we received programme and bistorical notss on airframes and some engineering manpower effort data. While useful as background information this dsta did not contribute directly to our analysis.

Contractors

In order to obtain the largest poesible sample, we decided to include civil aircraft and engines developed primarily for civil aircraft. Our initial discussions witb contractors indicated the projscts for which some data was expected to be available, from the total potential of projects since 1946. Development and manufacture of engines licensed from abroad were excluded. Tbe projects selected were for 22 airframes and 20 named engines.

As expected, data on several of the older airframe projects had besn destroyed or were not otherwise obtainable, owing to the various mergers wbich had taken place in the industry.

/A

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A list of the turbine engines and airframes on which data were made available is given in Appendix D. Not all of these data were equally useful or complete.

6. USE OF DATA, RESULTS AND INTERPRETATIONS

In this section of the report we have listed some of the major general qualifications and reservations that must be taken into account when interpreting the results. This is followed by description of the use of the U.K. actual data, the results and the specific qualifications that must be applied, for each of the Rand cost elements.

6.1 Method of Analysis

In essence, the terms of reference for this study required us to compare data on the time and cost of British aerospace projects with the data embodied in reports published by the Rand Corporation. Our analysis has concentrated on Rand reports RM-4845-PR and RM-4670-PR, which contain cost estimating relationships for airframes and aircraft turbine engines.

The data available on post war British projects is discussed in Section 5 of this report. As the Committee anticipated, these data have several important limitations. The number of U.K. projects is statistically small, it contains civil as well as military types and the definition of time and cost areas varies significantly both between the British and American samples and within each of these samples.

Partly because of these limitations there are substantial difficulties in making valid comparisons between the two samples. We spent some time examining the possibility of deriving cost estimating relationships for U.K. projects which could be compared with the corresponding relationships for American projects.

However, we did not consider this the most useful approach, partly because the limitations of the U.K. data reduce the validity of any derived cost/estimating relationship and partly because the comparison of one generalisation with another compounds the approximations inherent in each. For similar reasons we explored and discarded several alternative approaches.

We concluded that the most valid and informative basis for comparison was to use the Rand cost estimating relationships to predict what it would require in the U.S. (in terms of manhours and/or dollars) to develop and manufacture those U.K. airframes and engines for which we had actual manhour or cost data. This limited the degree of approximation since it compared generalised American data with specific data on U.K. projects, undistorted by statistical processing. Subsequently ratios were calculated which compared the actual manhours or cost expended on each U.K. project with the manhours or cost predicted by the U.S. formulae.

6.2 Presentation of Results

In presenting the results of our investigations we have had to compromise between ensuring the commercial security of the data supplied to us and preserving the usefulness of the results. In order to achieve this delicate balance we have quoted the results as the range of ratios of U.K. actuals to U.S. predicted results. We have also shown the arithmetic mean and, where meaningful, the standard deviation across the sample of U.K. projects.

During our analysis, it became apparent that the validity of certain data was questionable. We have therefore prepared two sets of results - one unedited and the other edited. The exclusions for the edited results have been made where it is known that the data supplied was dubious or that the definitions did not correspond closely with the Rand definitions. For example, the customer requirements for some civil airframes could not be eliminated from the data. As their inclusion overrides the effect of the learning curve they have been excluded from the edited results.

Some airframes and engines have been excluded even from certain categories of the unedited results. For example, on the analysis of Engineering Manhours, one airframe

/showed

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showed that U.K. had only expended 20% of the predicted manhours. When this was queried with the contractor it was doubtful whether all the manhours had been included or not.

6.3 General Qualifications

(1) The Rand Cost Estimating Relationships (C.E.R.'s) were specifically designed to be used for "long-range parametric planning studies". They may not therefore be accurate for use in international comparisons of productivity.

(2) The Rand C.E.R's were all derived from military airframes and aero-engines which had been manufactured in substantial quantities, and at high rates of production. In order to obtain a sufficiently large U.K. sample, civil aircraft have had to be included and in fact are in the majority. Further the numbers of aircraft produced in the U.K. sample ranged from 28-540 which is significantly lower than in the Rand sample. In this context it is unfortunate that we were unable to obtain the data for the Hawker Hunter as over 1,500 of these aircraft were produced.

(3) Due to the greater U.S. requirements the number of types of aircraft and engines developed has been larger than in the U.K. In consequence the advances in the "state of the art" in the U.S. appears to have been in smaller steps than in U.K. This must inevitably be reflected in the C.E.R's and in consequence produce results unfavourable to U.K. in any comparison based on them.

(4) The interpretation of definitions, the exclusion of certain aircraft data due to anomalies, the definition of a family of aircraft or engines and the adjustments made to cover major modifications are all open to question. We have had to make our own interpretations to cover these, which may not correspond exactly with the Rand interpretations. We have not separated out the effects of major modifications on any of the tables and thus the ratios of U.K./U.S. for any of the C.E.R's may be inflated to the extent of the modifications. However to indicate the effect of major modifications we have calculated ratios relevant to the data for the first mark of some airframes. These are obviously undistorted by any major changes. The results only materially affect the lowest ratios for Engineering and Manufacturing hours which reduce from 0.9 each to 0.7 for Engineering and 0.6 for Manufacturing.

(5) The collection of the U.K. actual data has necessitated the Contractors delving into past history as far back as 1945. Obviously under these circumstances it is not possible to guarantee the accuracy of the data or its conformity with the Rand definitions. We did not have the opportunity of checking the accuracy of the data supplied by contractors.

(6) There must be differences between the methods of funding, development concept, purchasing, service participation, testing etc. in the U.S. and U.K. which will be reflected in relative costs. We have no evidence as to the effect of these differences and can merely comment as to their existence.

(7) The combination of parameters of the U.K. airframes and engines may not be applicable to the Rand formulae.

6.4 Conversion Indices

(1) Dollars

All conversions of dollars to pounds sterling have been made at the rate of $2.80 = £1. This was the rate of exchange applicable in both 1962 and 1964 which were the base year dates for comparison of airframes and engines respectively.

(2) Materials

All materials have been converted to the base year cost 1962 for airframes, using the Ministry of Technology Index Numbers of Costs of Purchased Materials for the Aircraft Industry. This index was based on the 1954 census of production and was found to be correct against the 1958 census. It is now out of date against the 1963

/census

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census but has not been revised to take this into account. However, as there is a relatively small yearly movement in the index, it is thought to be sufficiently accurate for the purpose. Details of the Index are given in Appendix F.

(3) Engines

Both the Development and Procurement data were normalised to the base year 1964 using the Ministry of Technology's index of aircraft workers' hourly earnings (see Appendix F). This was used as it was found to correspond to the actual direct hourly wages supplied by the contractors and was available for a longer period.

(4) Rates per hour

Where possible the average overall rates for each category, applicable in 1962, have been used to convert their respective manhours to costs. These rates are not available to the Ministry and we have therefore not quoted them. Where the data has been given to us only in terms of yearly cost we have had to use the Ministry of Technology's index of hourly earnings where the data includes material we have used the index combined input costs which is a combination of the material and hourly earnings index. (See Appendix F for details).

6.5 Airframes

6.5.1 Engineering

Basis of Results

The Rand C.E.R. is expressed in hours and subsequently converted to dollars using an Engineering rate per hour. There is no complication in normalising the data to a base year. The Engineering hours in the Rand memorandum have been subdivided into initial and sustaining engineering by plotting the cumulative engineering hours against the cumulative quantity of airframes. We did not have sufficient data to carry out this subdivision except for certain airframes where we only had the actual Engineering hours up to first flight. This approximates to the Rand definition of initial engineering.

The main adjustment that Rand made to their Engineering data before establishing the C.E.Rs was to attempt to exclude the effect of major modifications. We have examined the U.K. actual data and on some airframes it is simple to exclude the hours for a different mark of airframe. On others it is not possible to so segregate. A second difficulty occurs in the definition of what constitutes a major modification. Excluding the modifications was clearly an arbitrary process and gave less realistic results. Their effects were therefore included and the ratio of U.K. to U.S. manhours is inflated to the extent of the major modifications.

/Results

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Results

$$\text{Ratios} = \frac{\text{Actual Hours or Cost}}{\text{Calculated Hours or Cost}}$$

	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	No. of Airframes in sample		
					Military	Civil	Total
UNEDITED RESULTS							
Initial Engineering hours	0.8	1.3	1.05	-	1	1	2
Total Engineering hours	0.9	2.1	1.26	-	2	6	8
Total Engineering Cost	0.2	0.7	0.38	-	2	7	9
EDITED RESULTS							
Total Engineering hours	0.9	1.3	1.14	0.19	2	5	7
Total Engineering Cost	0.2	0.4	0.35	0.08	2	6	8

Interpretation of Results

The Rand C.E.Rs are based on military airframes and military parameters. Civil airframes, which are included in our sample, are normally designed to different parameters, which may influence the results. In addition civil airframes are subject to customer requirements such as special cockpit layouts, cargo doors and handling equipment, "bus stop" facilities etc. All of these require re-designing which inflates the actual U.K. manhours.

6.5.2 Development Support

Basis of Results

The Rand definition of Development Support includes two components; the first includes the manufacturing labour and material required to produce mock-ups, test parts etc. and the second comprises a non-recurring element of material and purchased equipment due to the vendors charging their development costs to initial contracts. The data on material costs that we have received does not lend itself to this analysis and therefore this component of development support has had to be excluded.

/Results

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Results

$$\text{Ratio} = \frac{\text{Actual Cost}}{\text{Calculated Cost}}$$

	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	No. of Airframes in sample		
					Military	Civil	Total
UNEDITED RESULTS							
Development Support Cost	0.2	0.8	0.37	-	1	7	8
EDITED RESULTS							
Development Support Cost	0.2	0.5	0.30	0.10	1	6	7

Interpretation of Results

The Development Support equation is only expressed in dollars and therefore all the U.K. data has had to be converted to a base year. The Rand equation is for $13.6 per Initial Engineering hour which is the mean of their sample. The sample however shows a range from $9.12 to $19.59 per Initial Engineering hour, a factor of over two to one.

The edited result indicates that the U.K. cost is 30% of the U.S. cost. If the difference between the respective overhead ratea is taken into account then the U.K. figure is about 75% of the U.S. cost. This would leave approximately 25% to cover the material development cost component which has been omitted in the actual U.K. figures.

6.5.3 Flight Test

Basis of Results

The Flight Test equations are expressed in 1962 $ and therefore all the costs incurred have had to be converted to this base year. In all cases the hours have been converted to cost at the base year rate. Where material has been shown on a year to year basis it has been adjusted using the material index. Where material has been shown as a lump sum the year has been estimated and then adjusted.

Results

$$\text{Ratio} = \frac{\text{Actual Cost}}{\text{Calculated Cost}}$$

	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	No. of Airframes in sample		
					Military	Civil	Total
UNEDITED RESULTS							
Flight Test Costs	0.2	1.2	0.50	-	2	5	7
EDITED RESULTS							
Flight Test Costs	0.2	0.6	0.39	0.13	1	5	6

/Interpretation

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Interprstation of Results

The Flight Test C.E. Rs contain one extra factor, the numher of Flight Test Aircraft, in addition to the normal parameters of wsight and speed. The cost calculated from this equation is almost directly proportional to the numher of aircraft used in Flight Test. This means that one would have a 2:1 ratio of predicted cost if one used 10 aircraft over one year against 5 aircraft over two years of Flight Testing. This does not appear logical as the cost of the Flight Test aircraft are excluded. The C.E. Rs may give perfectly valid results for military aircraft when the purchaser determines the number of Flight Test aircraft within a small range, but it may not be valid for civil aircraft.

Secondly the Rand definition of Flight Testing is in three categories only the first of which is normally carried out by the U.S. contractor. This may not correspond to U.K. practice for military aircraft and does not apply for civil aircraft.

6.5.4 Tooling

Basis of Results

The Rand C.E. Rs are expressed in manhours and therefore no conversion is required. No mention is made in the Rand Report of the material cost of tooling and this has therefore been omitted; it is relatively insignificant anyway. The Rand definition includes the hours spent on Production Planning. In no case was it possihle for us to obtain the Production Planning bours as they are normally included in ths manufacturing overhead.

Results

$$\text{Ratios} = \frac{\text{Actual Hours or Cost}}{\text{Calculated Hours or Cost}}$$

	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	No. of Airframes in sample		
					Military	Civil	Total
UNEDITED RESULTS							
Tooling Hours	0.9	3.1	1.67	-	3	4	7
Tooling Cost	0.4	1.4	0.70	-	3	6	9
EDITED RESULTS							
Tooling Hours	0.9	1.8	1.43	0.31	2	4	6
Tooling Costs	0.4	0.8	0.61	0.14	2	6	8

Interpretation of Results

Despite tbe fact that the U.K. ratio is favoured to the extent that Production Planning hours are omitted this ratio is worse than any other category. Possihle reason for this is that in the U.K. some airframes have been manufactured in small quantities in different locations; the frsquency of modifications relative to the number of airframes produced may he higher than in the U.S.: the utilisation of tools due to quantity only may be lower in ths U.K.

Further it is possible tbat the Rand formula is insensitive to low rates of production such as are normal in the U.K.

/6.5.5

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6.5.5 Manufacturing Labour

Basis of Results

The Rand C.E.Ra are expressed in manhours and these have been converted at the 1962 rate for the cost equation. For the cost equation only it is necessary to add two Rand results, namely the cost of manufacturing and the cost of quality control.

For manhour comparisons we have calculated two ratios: the first is the ratio of the total calculated manhours to produces all the aircraft compared with the actual total manhours including sub-contracting. The second ratio is the calculated unit manhours compared with the actual hours taken for the final airframe.

Where we have only received data for part of the production quantity we have calculated the equivalent of this from the Rand C.E.Rs. Where we have only had data for a batch of airframes made later at a second factory, ws have calculated these as a second batch. This is certainly approximate but to treat it as the first batch produced would be even more unrealistic, as it assumes no learning or experience is transferred from one factory to the other. One airframe was excluded from the sample because, on either assumption, it came well outside the range of results quoted.

Results

$$\text{Ratios} = \frac{\text{Actual Hours or Cost}}{\text{Calculated Hours or Cost}}$$

	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	No. of Airframes in sample		
					Military	Civil	Total
UNEDITED RESULTS							
Total Manufacturing Labour Hours	0.9	2.0	1.36	-	6	9	15
Final A/C Manufacturing Labour Hours	1.1	4.0	1.66	-	6	9	15
Total Manufacturing Labour Cost including Quality Control	0.4	0.9	0.60	-	6	9	15
EDITED RESULTS							
Total Manufacturing Labour Hours	0.9	1.6	1.25	0.20	6	5	11
Final A/C Labour Manufacturing Hours	1.1	1.9	1.36	0.25	6	5	11
Total Manufacturing Labour Cost including Quality Control	0.4	0.7	0.54	0.06	6	5	11

Interpretation of Results

In certain cases the contractors havs been able to extract the hours due to customer requirements for civil aircraft. For other airframes the contractora bave not been able to differentiate them. In the latter case the learning curve for production is much flatter, the manhours being dictated by the particular customer requirements rather than those predicted by the slope of the normal learning curve.

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In the Rand C. E. Rs the method of catering for Engineering changes on manufacturing hours is to increase the hours by 11%. Rand admit that this is a crude adjustment with a standard deviation of ± 50%. The correct adjustment for the U. K. might be considerably higher as the incidence of Engineering charges relative to the number of airframes produced is very high, and therefore the effect of learning has less time to make itself felt before a change is made.

The U. K. results for costs include the cost of Production Planning which, on the Rand definition, should be included in tooling.

The total manufacturing hours on the edited results shows that the U. K. requires 25% more labour than the U. S. overall, and further that the U. K. requires 36% more labour for the final airframe produced. This would indicate that the learning curve in the U. K. flattens out, whereas according to Rand their unit curve continues at 75%. Whilst this is in general true, five airframes in the edited sample show a small reverse trend, i. e. the ratio of the last airframe is less than the ratio of the total. This small reversal is swamped however by the larger increase for the other airframes.

6. 5. 6 Manufacturing Material

Basis of Results

The Rand results are expressed in 1962 dollars and so all the U. K. results have been converted to 1962 rates using the Ministry of Technology Aircraft Material index. As material must be ordered prior to the completion of the airframe we have adopted the same basis as Rand and pre-dated the material cost by 1-1½ years.

Results

$$\text{Ratios} = \frac{\text{Actual Costs}}{\text{Calculated Costs}}$$

	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	No. of Airframes in sample		
					Military	Civil	Total
UNEDITED RESULTS							
Manufacturing material costs	0. 5	3. 0	1. 44	-	4	7	11
EDITED RESULTS							
Manufacturing material costs	0. 5	0. 7	0. 61	0. 09	4	1	5

Interpretation of Results

The U. K. material costs are inflated by the vendors' development costs as outlined under Development support. They are also increased by the customer requirements for some civil aircraft. In addition the accuracy of the final costs is open to question due to difficulties in definition for civil aircraft and due to some material costs being quoted at average cost for batches of aircraft.

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6.6 Turbine Engines

6.6.1 General Comments

All the Rand C.E.Rs are expressed in constant 1964 $ and therefore no direct comparison of productivity is possible. In order to overcome this we have calculated an approximate productivity ratio by multiplying the calculated U.S. $ converted to £ (at $2.80 = £1) by the ratio of U.K. to U.S. direct hourly rates in 1964. We are therefore comparing the calculated results expressed in U.K. labour cost terms with the actual U.K. results.

The Rand data was converted to a base year by using the ratio of direct hourly wages only. This method ignores the increase in overheads and cost of materials. In order to allow for the admitted rise in overheads Rand have produced two sets of data, the second of which includes an additional 2% year to year adjustment of the data. We have made all our comparisons against the 2% adjusted data.

6.6.2 Development Costs. Turbine Engines

Basis of Data

The U.K. data has been converted to a base year of 1964 using the Ministry of Technology Index of hourly earning of aircraft workers. The development cost has been calculated for the final thrust obtained by the engine in its ultimate mark. One difficulty was experienced in the definition of a family of engines. In two cases engines with the same generic family name have been split and taken as two separate engines, as this appeared more consistent with the Rand definition.

Results

$$\text{Cost Ratio} = \frac{\text{Actual Cost or Price}}{\text{Calculated Cost}}$$

Approximate Productivity Ratio =

$$\frac{\text{Actual Cost or price}}{\text{Calculated Cost}} \times \frac{\text{U.S. direct rate per hour \$}}{\text{U.K. direct rate per hour \$}}$$

	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	No. of Engines in sample
UNEDITED RESULTS					
Development Cost	0.18	0.59	0.42	-	12
Development Effort (Productivity)	0.46	1.49	1.05	-	12
EDITED RESULTS					
Development Cost	0.20	0.58	0.41	0.12	9
Development Effort (Productivity)	0.50	1.47	1.03	0.31	9

Interpretation of Results

As the results are all expressed in monetary terms and the method of normalising the data to the base year is by direct wages only, the accuracy of the results is dubious and can therefore only be used as a guide. Further the ratios for turboprop engines are considerably higher than those for turbojet engines although all have been treated on the same basis.

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In their analysis Rand have excluded the cost of development of civil engines. In our sample both civil and military development costs have been included partly to increase the size of the sample and partly because they were imposaible to separate on some engines. Anyway on some engines the military mark was derived from the civil version and the exclusion of the civil development costs would clearly be misleading in these cases.

6.6.3 Procurement costs

Basis of Results

The U.K. data was converted as for development costs. The costs were calculated by finding the average cost of each mark and thrust of the engine and multiplying this by the number of engines produced of the mark. In determining the average cost of each mark the thrust and cumulative quantity produced to date were taken as this takes into account the learning curve effect.

One curious anomaly was discovered, namely that when the cost of an engine was calculated with afterburner the Rand formula predicted a lower cost than for the same engine without afterburner at reduced thrust. For example an engine with a thrust of 10,000 lb. without afterburner for a quantity of 500 off would have a predicted cost of $303,000 each. The same engine with the addition of an afterburner with a thrust of 13,000 lb. would have a predicted cost of $289,000. Either the U.S. must obtain more additional thrust due to the afterburner i.e. about 40% to break even, or the calculation of the increased thrust is on a different basis. Accordingly we have based all our calculations on the cost of engines without afterburner.

Results

$$\text{Cost Ratio} = \frac{\text{Actual Cost or price}}{\text{Calculated Cost}}$$

Approximate Productivity Ratio =

$$\frac{\text{Actual Cost or Price}}{\text{Calculated Cost}} \times \frac{\text{U.S. direct rate per hour \$}}{\text{U.K. direct rate per hour \$}}$$

	Lowest Ratio	Highest Ratio	Mean	Standard Deviation	No. of engines or marks in sample
UNEDITED RESULTS					
Procurement costs	0.21	0.96	0.44	-	23
Procurement effort (Productivity)	0.50	2.42	1.12	-	23
EDITED RESULTS					
Procurement costs	0.21	0.64	0.38	0.14	18
Procurement effort (Productivity)	0.50	1.64	0.96	0.37	18

Interpretation of Results

The same qualifications for development apply to the procurement results.

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7. ACKNOWLEDGEMENT

We wish to take this opportunity of recording our appreciation of the helpful co-operation we have received from Mr. H. J. Blanks, Secretary to the Committee. We would also like to thank the staff and management of the various contractors, and officials of the Ministry of Technology, for their efforts to provide relevant data for this study.

/APPENDIX A

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APPENDIX A TO ANNEX D

TERMS OF REFERENCE

1. To examine the data contained in reports of the Rand Corporation on the time and cost of engineering, tooling and production for post-war airframes and aero-engines in the U. S. A. The following reports are particularly relevant:

(a) RM-4845-PR, May 1966, Cost-Estimating Relationships for Aircraft Airframes.

(b) RM-4670-PR, November 1965, Aircraft Turbine Engines - Development and Procurement Cost.

2. To examine the data held by the Ministry of Technology, by associsted Ministries and by the major British contractors on the time and cost of corresponding activities for comparable post-war projects in the U. K.

3. To make such valid comparisons as are possibls between these sets of data and to determine whether these comparisons indicate significant differences in the productivity of the aerospace industries in the two countries.

4. If it appears that significant differences in productivity do exist, to put forward proposals for further investigations which would determine the causes of these differences and the most suitable corrective measures.

5. To prepare a report describing the source data, the analyses, the conclusions drawn from comparisons of British and American data and the consultants' recommendations for further investigations, and to submit twenty copies of the report to the Secretary of the Elstub Committee.

/APPENDIX B

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APPENDIX B TO ANNEX D

COST ESTIMATING RELATIONSHIPS

AIRFRAMES

FROM RAND MEMORANDUM R. M. 4845 - PR ABRIDGED

W = Gross take off weight in pounds

S = Max speed in knots at best altitude

P = Max sea level thrust in pounds or E. S. H. P. x 2. 5

N = Quantity of aircraft produced

n = Number of flight test aircraft

R = Production rate per month

All costs are in constant 1962 $

Initial Engineering Hours = E1

$$\text{Log } E1 = 0.90 + 0.55 \text{ Log } S + 0.88 \text{ Log } P$$

Cumulative Engineering Houre = Ecum

$$\text{Log Ecum} = \text{Log } E_1 + 0.2 \text{ Log } N$$

Development Support Coet = $ D

$$D = \$\ 13.6 \times E_1$$

Flight Test Operations Costs = $ F

$$\text{Log } F = -0.30 + 1.1 \text{ Log } n + 0.80 \text{ Log } W + 0.90 \text{ Log } S$$

Tooling Hours 1 Aircraft per month = T_1

$$\text{Log } T_1 = -0.91 + 0.84 \text{ Log } W + 1.07 \text{ Log } S$$

Tooling Hours R Aircraft per Month = TR

$$\text{Log TR} = \text{Log } T_1 + 0.4 \text{ Log } R$$

Cumulative Tooling = Tcum

$$\text{Log Tcum} = \text{Log TR} + 0.14 \text{ Log } N$$

Manufacturing Labour Hours for 100th Airframe = H100

$$\text{Log H100} = 0.16 + 0.74 \text{ Log } W + 0.43 \text{ Log } S$$

Manufacturing Labour Hours for Nth Airframe = HN

$$\text{Log HN} = \text{Log } 8.76 + \text{Log H100} - 0.415 \text{ Log } N$$

Quality Control Cost for Nth Airframe = QN

$$QN = 0.14\ HN$$

/Manufacturing

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Manufacturing Material Costs for 100th Airframe = $ M100

$$\text{Log } M100 = -0.77 + 0.78 \text{ Log } W + 0.86 \text{ Log } S$$

Manufacturing Material Costs for Nth Airframe = $ Mn

$$\text{Log } Mn = \text{Log } 2.17 + \text{Log } M100 - 0.188 \text{ Log } N$$

TURBINE ENGINES

FROM RAND MEMORANDUM R. M. -4670 - PR ABRIDGED

NOTE:- All equations include the 2% adjustment to cater for the increase in overheads and capital investment.

T = Max sea level thrust in pounds

E = Max equivalent shaft horse power

Q = Quantity produced

All costs are in constant 1964 $

Development Cost Turbojet Engines = $ Dj

$$\text{Log } Dj = \text{Log } 0.19573 + 0.72151 \text{ Log } T + 0.08101 \text{ Log } Q$$

Development Cost Turboprop engines = $ Dp

$$\text{Log } Dp = \text{Log } 2.60194 + 0.38361 \text{ Log } E + 0.08635 \text{ Log } Q$$

Procurement Cost Turbojet Engines with Afterburner = $ Pa

$$\text{Log } Pa = \text{Log } 0.14182 + 0.89842 \text{ Log } T - 0.14013 \text{ Log } Q$$

Procurement Cost Turbojet Engines without Afterburner = $ Pj

$$\text{Log } Pj = \text{Log } 0.26616 + 0.85599 \text{ Log } T - 0.13632 \text{ Log } Q$$

Procurement Cost Turboprop Engines = $ Pp

$$\text{Log } Pp = \text{Log } 3.87061 + 0.50599 \text{ Log } E - 0.11771 \text{ Log } Q$$

/APPENDIX C

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APPENDIX C TO ANNEX D

DEFINITIONS OF TERMS

The definitions of cost and man-hours given below are from the relevant RAND Reports. Where a clarification note is added, this has been obtained either from RAND personnel or from staff at contractors who have had detailed discussions with RAND engineers on other exercises.

Definitions of weight have been given in an attempt to ensure consistency by all sources of data, as it is an important element in the RAND formulae.

These definitions and notes have been the bases of our requests for data from all sources.

1. AIRCRAFT TURBINE ENGINES - DEVELOPMENT AND PROCUREMENT COST RM-4670-PR

Engine

An engine (and all of its military derivations and dash numbers) is assumed to be one basic engine model.

Cost

"Cost" is defined to include all labour, material, overhead, administrative and direct expenses and profit charged or expended by the contractor.

Clarification: as cost includes contractor's profit, it is therefore the engine price paid by the purchaser. Where non-British Government sales were made, a "notional" profit at a rate normally expected from Government contracts should be included instead of the actual profit.

Development Cost

The total expenses contributed to developing a new engine, plus the cost of continued performance improvement over time.

Development cost includes initial contractor preliminary design, subsequent engineering, prototype tooling, material, fabrication, assembly and bench testing of scale or full-size components or complete engines to and including qualification testing to acceptance specifications. Also included is the cost of production tooling.

Sustaining engineering involving factory liaison, training, preparation of maintenance manuals, etc. not considered as development but as part of production cost.

Procurement Cost

The total cost to fabricate and assemble complete engines including labour, materials, overhead and profit. Also included is sustaining tooling, factory liaison, acceptance testing and the preparation of supporting data such as maintenance manuals.

No development or product improvement costs are included in the overhead of production engines.

Clarification:

(a) The production rates quoted for engines must not include spare components, unless these amount to spare engines.

(b) In the case of turbo-jets, man-hours and/or cost data associated with jet pipes must not be included unless these are fitted with afterburners.

/(c)

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(c) Man-hour and/or cost data associated with the accessories normally required for a "clean" engine (engine to function within an aircraft) must he included. However, accessories which are only sometimes required by customers for further applications - such as air-conditioning, blown-flaps, etc. are not to be included in the data.

2. COST-ESTIMATING RELATIONSHIPS FOR AIRCRAFT AIRFRAMES RM-4845-PR

Engineering

Engineering hours include hours charged to the following kinds of activity:-

design studies and integration, engineering for wind tunnel models, mock-ups and engine test, test engineering, laboratory work on sub-systems and static test items and development testing; board hours; release and maintenance of drawings and specifications; shop and vendor liaison; analysis and incorporation of changes; materials and process specifications; and reliability.

Engineering hours not counted as airframe engineering hours include those charged to flight test, planning, ground handling equipment, spares, mobile training units and publications.

Clarification:-

loftsmen are included

the term "publications" means sales literature. Technical publications are included in "engineering"

programme engineers and value engineers are included

sub-contract engineering costs to be included by conversion at sub-contractors rates

Development Support

Development support is the name given to the non-recurring manufacturing effort undertaken in support of engineering during the development phase of an aircraft programme. The cost of development support is the cost of manufacturing labour and material required to produce mock-ups, test parts, static test items and other items of hardware, not including complete flight test aircraft, that are needed for airframe design and development work.

The development support cost is made up of two components:-

(i) a development support cost, consisting mainly of the cost of manufacturing labour and material associated with the engineering effort

(ii) a material cost component - the costs incurred by material vendors for tooling, set-up and development. This element of cost is not included in "Manufacturing Material"

Clarification:-

the cost of running wind tunnels is not included

any special tooling made by the contractor solely for development support is not included in development support but in Tooling

the term "material" includes not only raw material but components, parts and equipment, some of considerable complexity and requiring significant design and development work by the vendors

/Flight

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Flight Test

The flight test operations cost comprises all costs incurred by the contractor to carry out flight tests except the cost of test aircraft. It includes engineering planning and data reduction, manufacturing support, instrumentation, spares, fuel and oil, pilot's pay, facilities rental and insurance. Flight test costs incurred by the RAF or RN are not included.

Clarification: Flight Test Operations cost includes:-

route proving trials

testing production aircraft

inspection costs

crew training

costs of operating chase aircraft

Tooling

Tooling hours are defined as hours charged to the airframe for tool design, tool planning, tool fabrication, production test equipment, checkout of the tools, maintenance of tooling, changes and production planning.

Hours not directly attributable to airframe tooling, such as those tooling hours charged to ground handling equipment, spares, mobile training units etc. are excluded from the data base.

Clarification:-

tooling includes production planning

sub-contractor's hours are included at sub-contractor's rates

includes tooling required for development support

Manufacturing Labour

Manufacturing labour hours include those hours necessary to machine, process, fabricate and assemble the major structure (AMPR weight) of an airframe and to install purchased parts, government supplied equipment and off-site manufactured assemblies. AMPR manufacturing direct man-hours are also defined to include effort on those parts which, because of their configuration of weight characteristics are design controlled for the basic aircraft. These normally represent significant fractions of airframe weight and of the manufacturing effort and are included regardless of their method of acquisition. Such parts specifically include the following:-

landing gear oleo shock and actuating cylinders

all other actuating hydraulic cylinders

radomes, canopies and ducts

seats, passenger and crew

food preparation equipment such as galleys, stores and refrigerator units

fixed external tanks

The man-hours required to fabricate purchased parts and materials, such as are listed below under the definition of Manufacturing Material, are excluded from airframe manufacturing labour hours.

/Clarification:

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Clarification:-

sub-contractors hours included at sub-contractors rates

manufacturing labour cost includes the cost of assembling major systems e. g. engines, electronics and other equipment into the complete aircraft

Manufacturing Material

Manufacturing material includes the raw material, hardware and purchased parts required for the fabrication and assembly of the major structure of the aircraft. This includes equivalent in-plant material for off-site manufactured assemblies. Typical examples of manufacturing material (as listed in the AMPR reports in the USA) are the following:-

1. Raw materials in typically purchased forms and shapes (sheets, bars, rods, etc.)

2. Semifabricated materials in typically purchased forms and shapes (wires, cables, fabrics, conduits, tubings, sealing strips, fibreglass, windshield glass etc.)

3. Raw castings and forgings.

4. Standard hardware items e. g. nuts, bolts, bearings, rivets, bushings etc.

5. Manufactured proprietary clips, fasteners, hose clamps and assemblies, seat bolts, etc.

6. Standard and proprietary valves, cocks, hydraulic and plumbing fittings and fixtures.

7. Standard electrical fittings.

8. Standard and proprietary electrical manufactured products (motors, transformers, inverters, alternators, lights, voltage regulators, circuit breakers, automatic switches and controls, horns, intercom devices, etc.)

9. Pumps, (fuel, hydraulic, pressurisation, feathering, water injector etc.)

10. Other major purchased equipment normally supplied by the airframe manufacturer, actuators, environmental systems, electrical generating systems, auxiliary power units, crew provisions, etc.

Costs of embodiment loan items are not included as material costs.

Quality Control

Quality control is defined as the labour necessary to inspect all of the work performed under the manufacturing labour category plus inspection of manufacturing materials including raw materials, standard parts and purchased equipment.

3. AIRCRAFT WEIGHT - AMPR WEIGHT

AMPR Airframe Unit Weight is used in U. S. A. as a consistent basis for comparison of airframe computations in the Aeronautical Manufacturers' Planning Reports. It is defined as follows for conventional aircraft:-

Weight empty, minus the weight of the following items, regardless of their method of acquisition (the weight of an alternative equipment item not included in the basic design is not to be included in this weight empty figure):-

Items of Deduction:

1. Engine (dry weight)

2. Trapped fuel, coolant to the extent included in the weight empty

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3. Propeller hubs, blades, power control, governor (not including installation parts and wiring)

4. Wheels, brakes, tyres and tubes

5. Auxiliary power plant

6. Turbo superchargers (not including controls, intercoolers, lubricating systems, etc.)

7. Radio receiver transmitters, radar and removable units (not including installation parts and wiring)

8. Starter (not including shafts, gear boxes, wiring etc.)

9. Battery (not including containers or other items)

10. Generators (not including control boxes etc.)

11. Turrets and power-operated gun mounts

12. Electronics and fire control systems (not including installation parts and wiring)

13. Instruments

14. Air condition and pressurisation units (not including ducts, wires, or brackets, manufactured or installed by the contractor)

15. Rubber or nylon fuel cells (only the weight of the bag).

The AMPR Airframe Unit weight concept is not synonymous with the concept of weight empty minus Government Furnished Aeronautical Equipment items, i.e. embodiment loan items. Only the above specified items are deducted from the weight empty.

/APPENDIX D

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APPENDIX D TO ANNEX D

PROJECTS CONSIDERED

Data, in a form which could be used to compare with RAND equations, were obtained on the following projects.

1. Airframes

Aircraft	Gross Take-off Weight (1000 lbs)	Max. speed at Best Altituds (knots)	Max. Thrust or equivalent thrust (1000 lbs)	Date of First Flight
Britannia	155-185,	419	42.4	Aug. '52
Lightning	-	-	-	Aug. '54
Canberra	41-51	450-575	12-22	May '49
V.C. 10	299-335	505	84-90	June '62
B.A.C.1-11	78.5	470-475	20.82	Aug. '83
Vanguard	146.5	428	49.85	Jan. '59
Viscount	48.89	300	15.5-19.9	July '48
Valiant	138	490	40	May '51
Gnat	9.35	620	4.2-4.5	Aug. '59
Vulcan	-	-	-	Aug. '52
Sea Vixen	38.42-45.47	810	22.5	Mar. '57
H.S.125	21.2-21.7	410	8-5.72	Aug. '62
H.S.748	31-44.5	234-249	8.5-9.5	June '80
H.S.1154	-	-	-	N.A.
Trident	115-130	515	29.55-34.2	June '62
Comet 4	162	450	42	Mar. '58
Gannet	20.3-21.8	250-260	7.0-7.5	Sept. '49

Where blanks are shown in this table, the data is classified, and therefore has not been included.

/2.

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2. Engines

Name	Thrust 1000 lbs	S.H.P.
Derwent	3.6	
Avon	6.24-16	
Spey	11.15	
Nene	5-5.4	
Conway	16.9-20.16	
Dart		2120-2970
Tyne		5095
Olympus (100 - 300)	11-20	
Pegasus	15-19	
Viper	1.64-3.41	
Orpheus	4.4-5	
Sapphire	11-14.5	
Double Mamba		2540-4200
Goblin	3-3.5	
Ghost	4.75-5.3	
Gyron Junior	7-14	
Proteus		3960-4397

/APPENDIX E

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APPENDIX E TO ANNEX D

FORM OF DATA REQUIRED

Data was requested from all sources in the following detail and format.

Airframes

By aircraft Type:

Variants
Key Dates (Development)
- initial studies started
- I. T. P.
- First Flight
- C of A/CA Release

Key Dates (Production)
- First Flight 5th, 10th, 30th aircraft or by batch.

Weights
- gross take off
- A. M. P. R.
- B. A. M. P. R.
- Contractor's Supply Weight

Speeds
- Max speed (knots) at best altitude

Thrust
- Max. sea level static (or equivalent)

Production Rate at each Plant
Cost Allocation sheets for each year
Brief Historical Notes

Cost and/or Hours, to RAND definitions (see Appendix C) By Years:

Engineering
- Hours

Flight Test
- Engineering hours
- Engineering rate
- Engineering overhead rate
- Development hours
- Development rate
- Development overhead rate
- Inspection hours
- Inspection rate
- Inspection overhead rate
- Materials

Tooling
- Tool design hours
- Tool manufacture hours
- Tool planning hours
- Production planning hours

/By

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By each Aircraft:

Manufacturing labour
- detail hours
- assembly hours
- finals hours

Manufacturing Material

- Cost (£)

Turbine Engines

Engine Designation
Type; turbojet or turboprop
Max. sea level static thrust (or equivalent), with and without afterburner
Number of development engines
Hours to type test and date of achievement
Hours to flight clearance and date of achievement
In-service date
Total number of production engines
Brief historical notes and special technical characteristics

Cost data to RAND definitions (see Appendix C) By Years:

Development
- Cost
- Average direct hourly rate
- Average indirect/engineering rate
- Overhead rate

Procurement
- Cost
- Average direct hourly rate (production)
- Average indirect rate (production)
- Overhead rate

By engine quantity (learning curve data)
- number per batch
- cost per batch

/APPENDIX F

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APPENDIX F TO ANNEX D

CONVERSION INDICES

The indices given below were used for adjustment of costs to a 1962 basis for airframes and a 1864 basis for turbine engines.

	Ministry of Technology Hourly Aircraft Earnings		Ministry of Technology Purchased Materials	Ministry of Technology Combined Wage and Materials
Year	Airframes	Engines	Airframes	Airframes
1945	2.43	2.71	2.46	2.36
1946	2.23	2.47	2.46	2.21
1947	2.23	2.47	2.13	2.11
1948	2.28	2.55	1.91	2.02
1949	2.26	2.51	1.80	1.81
1950	2.13	2.37	1.82	1.81
1951	2.00	2.23	1.47	1.63
1952	1.81	2.02	1.32	1.48
1953	1.86	1.85	1.31	1.43
1954	1.58	1.76	1.28	1.39
1955	1.44	1.60	1.22	1.30
1956	1.36	1.52	1.13	1.21
1957	1.31	1.45	1.08	1.15
1958	1.23	1.36	1.07	1.12
1959	1.20	1.33	1.07	1.10
1960	1.10	1.22	1.05	1.08
1961	1.03	1.14	1.02	1.02
1962	1.00	1.11	1.00	1.00
1863	0.98	1.09	0.99	0.99
1964	0.90	1.00	0.98	0.85
1965	0.82	0.91	0.83	0.89
1986	0.78	0.85	0.89	0.83
1967	0.70	0.79		

/APPENDIX G

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APPENDIX G TO ANNEX D

AIRFRAME PRODUCTIVITY COMPARISONS

In this appendix we show the method used to calculate the apparent increase in Productivity per man due to the longer production runs in U. S. Subsequently these figures have been used to factor the normal global measures of relative productivity to produce a modified global measure which is related to U. K. production quantities.

Assumptions: (1) The production runs have been taken from the Plowden Report.

(2) The normally accepted range of global measures of relative productivity between U. S. and U. K. is 2.5 to 3.0 to 1.

(3) To eliminate the effect of different learning curve slopes the slope of the unit learning curve has been assumed to be 75% as per the Rand memorandum on airframes.

(4) In the tooling equation the rate of production has been assumed to be proportional to the quantities produced.

PRODUCTIVITY COMPARISONS

	Relative Total Cost or Hours				Apparent Productivity		Modified Global Index				Actual Ratios	
	Military		Civil				Military		Civil			
	U. S.	U. K.	U. S.	U. K.	Mil.	Civil	2.5	3.0	2.5	3.0	Unedited	Edited
Production Nos.	530	177	320	68								
Engineering Hours, proportional to $N^{0.2}$	3.5	2.8	3.2	2.3	2.4	3.3	1.1	1.3	0.8	0.9	1.3	1.1
Development Support Costs	1	1	1	1	3.0	4.7	0.8	1.0	0.5	0.6	0.9	0.8
Flight Test Costs	1	1	1	1	3.0	4.7	0.8	1.0	0.5	0.6	1.3	1.0
Tooling Hours proportional to $R^{0.4} \times N^{0.14}$	3.7	2.1	4.2	1.8	1.7	2.0	1.5	1.8	1.2	1.5	1.7	1.4
Total Manufacturing Hours, proportional to $\frac{1}{1-b} N^{-b}$ approx.	0.13	0.20	0.16	0.3	1.6	1.9	1.6	1.9	1.3	1.6	1.4	1.3

Where:- N = No. of Airframes produced
R = Rate of Production
b = Slope of learning curves

/PRODUCTIVITY

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PRODUCTIVITY COMPARISONS

Explanation

Taking the Engineering hours as an example:

(1) Relative total Cost = $N^{0.20} = 530^{0.20} = 3.5$ etc.

(2) Apparent Productivity due to longer production runs.

The relative total cost is divided by the number of aircraft made to give a relative cost per airframe and then the U.K. figures are divided by the U.S. figures, i.e.

relative U.S. military costs each = $\frac{3.5}{530}$

" U.K. " " " = $\frac{2.8}{177}$

Apparent Productivity increase

$$= \frac{2.8}{177} \div \frac{3.5}{530} = \frac{2.8}{177} \times \frac{530}{3.5} = 2.39 \text{ for military airframes}$$

(3) The modified global index is calculated by dividing the normally accepted figure of 2.5 to 3.0 by the apparent Productivity increase due to longer production runs.

Modified index = $\frac{2.5}{2.39}$ to $\frac{3.0}{2.39}$ = 1.05 to 1.25 for military airframes

(4) The last column shows the results as predicted from the Rand formulae and have been taken from the tables of results in Section 2.3 of the report.

/APPENDIX H

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APPENDIX H TO ANNEX D

Ministry Branches Contacted

Aircraft Production Division

Project Time & Cost Analysis
DAP/Costs
APG (Plans)
Eng. P/Costs

Engine Research & Development Division

Eng RD 1(a)

Contracts Division

Directorate of Contracts (A)
Directorate of Technical Costs, TC(A) & TC(E)

Air (B) Division

Air B2

Air (C) Division

Central Statistics/Air Branch

Air C. 2A

The Directorate of Accounting Services and Central Statistics assisted by providing data required in the course of analysis.

/ANNEX E

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Annex E

Ref: Chapter 22

REPORT BY THE WORKING PARTY ON

PRODUCTION CONTROL

Prepared by:

Dr. T. A. Duerden,
British Aircraft Corporation Ltd.

Mr. P. Jefferson,
Hawker Siddeley Aviation Ltd.

Mr. J. E. B. Perkins,
Rolls-Royce Ltd.

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1. Introduction

2. Definition of the Function of Production Control

3. Production Control in the Industry

4. Solutions to the Problems of Production Control

5. Conclusions

Chart 1. Functions of Production Control

Chart 2. Functions of Production Control with effective use of Data Processing

Appendix 1. Scale of Production

Appendix 2. Technical Modifications

Appendix 3. Short Term Programming

Appendix 4. Example of Rationalisation of Production

Appendix 5. Policy of Progressing either to Shortages or Schedules

Appendix 6. Deciaion on Batching Quantitiea

Appendix 7. Lead Times for Manufacture

Appendix 8. Extension of Data Procesaing

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Annex E

Octoher, 1967.

ELSTUB COMMITTEE

REPORT BY THE WORKING PARTY ON PRODUCTION CONTROL

1. INTRODUCTION

The report has been prepared to outline the problems associated with the function of Production Control in ths induatry and to make recommendations with regard to future developments with particular reference to the more extensive use of improved techniques such as data processing.

The Working Party have not attempted to prepare a complete review of the paat history and present position of the industry with full supporting data but rather to comment apecifically on those areas which have presented a common prohlem and from thia information to make suggestiona as to ths future course of devslopment.

Whers neceasary, to demonstrate a particular point, statiatical data has heen given hut this has been kept to a minimum in order to restrict the size of the report and to allow completion in the time scale. If rsquired by the Committee the information could be extended on any particular aspect.

2. DEFINITION OF THE FUNCTION OF PRODUCTION CONTROL

The function of Production Control is:-

(a) to receive Engineering, Production Engineering and Commercial Instructions defining the product, the method of manufacture, the technical allocation of work and the requirementa in terma of quantity and delivery timescales;

(h) to interpret this data into the components, parts or materials required for the product and the datea hy which these are required. Iasue instructions for these requirements either internally within the Company or externally to outside Suppliera;

(c) to progress the manufacturing poaition against these instructions to the dates required to mset the overall programme for the projsct;

(d) to record the position and availability of the parts required;

(e) to amend the instructions in the light of changes and achievements hoth in manufacture and aupply.

Chart 1 showa a typical organisation of this function in induatry.

3. PRODUCTION CONTROL IN THE INDUSTRY

It is the view of the Working Party that the operation of a Production Control System in an established factory with a stabls commitment is a relatively simple exercise.

However, the Working Party considered that in the Aircraft Induatry thia ia not the case and in this section those factors which have the most significant impact on Production Control are identified and reviewed. In some cases detailed information ia aupplied in the Appendicea.

The Working Party have noted significant production differences hetween the airframe and aero-engins industriea. These major differences are firstly the total quantity of parta to he produced for ths end product which is an order of magnitude higher for aircraft, and aecondly the much larger component hatchss in aero-engine manufacturs. (Appendix 1 gives some of the relevant statistics.) However, the basic prohlems are fundamentally the aame.

/(a)

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(a) Volume of Parts to be Handled

The Working Party believe that the Committee will have already been adequately briefed as to problems associated with the volume of parts to be produced and the variety of skills involved. Therefore no attempt has been made to provide detailed information although some general figures will have been noted in Appendix 1.

(b) External Factors

Some of the more important factors outside the framework and responsibility of a Production Control Department have been considered by the Working Party to show the considerable effect that these have on Production Control problems; these are:

(i) Technical Modifications (Appendix 2)

(ii) Short Term Programming (Appendix 3)

(iii) Long Range Planning

The task of Production Control is directly affected by the efficiency of Short Term Programming or Long Range Planning and the impact of Technical Modifications.

While detailed consideration of these aspects is outside the terms of reference of this report, the significance of these items is such that the attention of the Committee is drawn to the comments made in the Appendices which have been prepared.

(c) Procurement from Outside Suppliers

The Aircraft Industry is dependent on the supply of a wide range of items from other industries. The degree of control that can be exercised over these Suppliers and their speed of response is substantially lower than can be achieved internally.

As indicated in the previous section the high rate of change is responsible for much of the difficulty experienced in controlling production, even if the items are manufactured internally.

For the reasons given above this control problem is magnified in the case of items obtained from outside Suppliers.

In addition, problems exist on the military side of the airframe industry by virtue of the major items of Government Furnished Equipment.

While this is a major problem it is considered as being outside the scope of this report although if required by the Committee more detailed consideration could be given to this aspect.

(d) Rationalisation in the Industry

Over the last decade Companies in the industry have been merged into larger units. This has led to varying degrees of rationalisation of manufacture with undoubted advantages which can occur from specialisation in particular processes or products.

Where a high degree of technical development is required or to effectively utilise sophisticated production techniques, there can be no argument that this can give substantial economic advantages in manufacture. However, it poses large scale production control problems if this work is to be effectively integrated.

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There has been, within the aero-engine industry, a marked growth in the economic size of manufacturing units specialising in particular areas of production and the organisation effect is shown in detail in Appendix 4 to demonstrate this point.

In the airframe industry, because of the different types of manufacturing problems and the smaller areas for specialisation, the degree of specialisation is not so marked. Rationalisation has tended to be more by type of process than type of component and has not made the same impact. However, the need to obtain the full economic benefit from the overall industrial rationalisation in the industry with its fluctuating work loads has necessitated the imposition of controls in balancing the load of projects between the different manufacturing units.

Therefore, while the degree of central production control attempted varies considerably and is most marked in the aero-engine industry, it is clear that in both cases the additional control problems imposed by the reduction in number of independent operating units in the industry have increased the scope of the production control task.

International Collaboration on major projects is a relatively recent development and is creating even further problems both in production and other areas of the organisation but this was considered too large an issue to be covered in this report.

(e) Creation and Operation of Systems of Control

The establishment and operation of efficient procedures to perform and maintain the functions of Production Control is of significant importance and the following aspects have been selected for comment in this report; details are given in the relevant Appendices.

(i)	Policy for Progressing either by Shortages or Schedules	(Appendix 5)
(ii)	Decisions on Batching Quantities	(Appendix 6)
(iii)	Lead Times for Manufacture	(Appendix 7)

The object is to give the Committee some impression of factors that need to be considered in operating an efficient system.

From this information it will be seen that some of the parameters that have been taken into account are particularly complex, particularly if related to the other aspects already covered in this section.

4. SOLUTIONS TO THE PROBLEMS OF PRODUCTION CONTROL

The solution of the inter-related problems identified in the previous section must depend on an improvement in the following four aspects of production control:-

(i) People

(ii) Organisation

(iii) Systems Design

(iv) Data Processing

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It is important to recognise that these in turn are inter-related factors and no significant improvements can be expected if they are implemented in isolation.

(a) Management and Staff

Historically the function of Production Control has been considered as basically a clerical operation and has exercised a small influence in the overall planning of the Companies.

Because of this and the fact that the work has been concerned with a vast paperwork operation and dealing with the day to day production pressures, there has been little desire on the part of management to improve the calibre of staff or for qualified individuals to select these departments for employment.

Progressively this view has been changing and the importance of an effective production control organisation has been accepted.

The technique required in investigating basic production procedures and the transfer of routine clerical work to the computers must change the type of staff.

The logical step by step thinking which is an essential criterion of success in this area, fits in uneasily with the rather untidy "hunch" management which has dominated the production control area in the aircraft industry as in many other industries.

In practice, it is of course necessary for a very considerable period of time (up to five years) to run both the new and old types of production control people to some extent in parallel. While the computer systems are being developed in operation with their inevitable snags, there will be a large number of production output crises which have to be handled without adequate paperwork and instruction by the old ad hoc techniques.

This combination of usage of highly trained staff, knowledgeable more in systems work, and the old rugged type of progress-men in the same organisation, places a very high demand on the senior production control managers.

The problem is aggravated by the fact that there is in certain sections of the industry an unfortunate history of past failures to use graduates effectively in production control which have been due to inadequate prior training before exposure to the normal high production pressure in the industry.

The failure to obtain adequately trained management in the production control area is probably one of the most serious competitive disadvantages in any direct comparison with U.S. industry.

(b) Organisation of Production Control

It is considered that the increasing complexity of the Production Control system in the industry described in Appendices to this report, necessitates a progressive review of the organisation structure.

Since apart from the introduction of more sophisticated tools such as the computer, which are changing the nature of the production control task, there has in addition been the rationalisation of manufacture within the industry.

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Under these conditions it is necessary to consider the establishment of an adequate central control, not only to establish the procedures outlined in the subsequent paragraphs in this section, but also to ensure the day to day control of production from a number of work centres or factories.

All the Companies concerned with this report have introduced to the varying extent required by their present projects and allocation of production in their factories, the concept of a centralised Production Control function, and this in turn has had an effect on the organisation at each of the factories.

While progressively the central organisations will need to be strengthened essentially to match the specialisation which occurs generally in the production organisation, the only conditions under which this work can be effectively organised is with the extensive use of data processing, linked with effective short term programming.

The organisations developed in the industry are substantially different at this stage and this is partly due to the importance placed on the economic advantages of production specialisation and the type production required.

(c) Systems Design

The operation of a more efficient Production Control Department is dependent on the development of adequate systems and some indication of the ultimate scope of these is given in Appendices 4-6.

The complexity of the parameters to be considered requires intensive operational research and systems design which will affect the overall Production Organisation.

Industry has concentrated a considerable effort in the last few years to design systems of control and has used where applicable the results of studies made in other industries or countries.

However, it is apparent that at this stage development has been constrained by the difficulty of operating effectively any form of complex system by conventional clerical methods due to the volume of work and in no case have systems been fully developed.

In no sense is this intended to indicate that overall the industry is lagging in this field, but it is apparent that overall in industry a considerable amount of work remains to be done. Undoubtedly one of the most important reasons why more effective progress has not been made, has been the difficulty of operating these systems once they are developed. The introduction of worthwhile extensions of data processing has a substantial effect on this field and this is the subject of the next section.

(d) Data Processing

The operation of effective production control procedures and the effective organisation of these systems is dependent on the use of data processing.

This is based on:

(i) The volume of different items to be handled.

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(ii) The complexity of the factors to be considered.

(iii) The need for effective up-to-date information on the production position.

Because of the importance of this aspect it has been dealt with in some detail and further information is given in Appendix 8; also Chart 2 is included to show the effect on a Production Control Organisation of the full use of a computer.

All Companies have made extensive use of data processing at their factories, although there is some variation in the extent of overall application as a result of the more recent mergers.

All the Companies are investing substantially in new equipment and in the associated systems work that is the necessary adjunct to this.

This investment is being made against the background that to date neither in Great Britain, nor in many cases in the U.S.A., can the economics be clearly demonstrated.

While the present second generation equipment has been adequate for a number of applications the extent of development has been controlled by equipment, the flexibility of operating systems, the availability of trained specialist staff and the general problem of education of all levels of staff and management.

However, the third generation equipment now available with provision for multi-programming and random access storage, also the development of data collection and interrogation equipment, should in time remove many of the equipment limitations on the present development of Production Control systems and provide greater flexibility when the necessary operating techniques are developed.

The Working Party noted that each of the Companies concerned had independently come to the conclusion that the specification for future systems would be defined by the line management of the departments using the data, rather than specialist departments, although these would still be available to support the work, in order to ensure the maximum practical value.

Also, each Company had found it necessary to set up internally intensive training courses for specialist staff and also general education courses for all levels of management.

5. CONCLUSIONS

(a) Excluding the question of external factors, introduction of improved control involves a close relationship between people, organisation, systems and data processing.

Although these issues are closely inter-related, the speed of development will probably be fundamentally limited by the availability of suitable people in all areas.

(b) The Working Party have reservations as to whether broadly the staff employed in Production Control is of adequate calibre for these developments. While the position has improved, the future developments will require a re-organisation of these departments and a considerable up-grading in the overall competence of the staff.

/(c)

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(c) Within the Companies concerned, plans are already being implemented to extend substantially the Data Processing equipment available. It is the view of the Working Party that little could be added in this field and currently the controlling factors will be the development of operating/executive programmes by the Computer Manufacturers and the development of systems by the Companies.

(d) Within the constraints of the equipment available we consider that reasonable progress is apparent in the last few years towards the setting up of suitable production control systems with automatic data processing.

Each Company concerned with this report has long term plans to advance this work even further, taking advantage of the developments in equipment which make this practical.

It should be noted that a number of specific problems are common not only across this industry but in all Engineering work. The Committee may wish to consider whether Industry can be supported in some manner, bearing in mind the substantial investment involved in terms of staff and equipment. This might possibly be carried out through the National Computer Centre, provided the work is of a practical nature.

(e) Management should consider whether in the light of the data prepared for this report, Production Control has an adequate voice in the overall Management planning in the industry, having regard to the complexities of the task and the effect of factors external to Production Control outlined.

/CHART 1

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CHART 1

REPORT ON PRODUCTION CONTROL

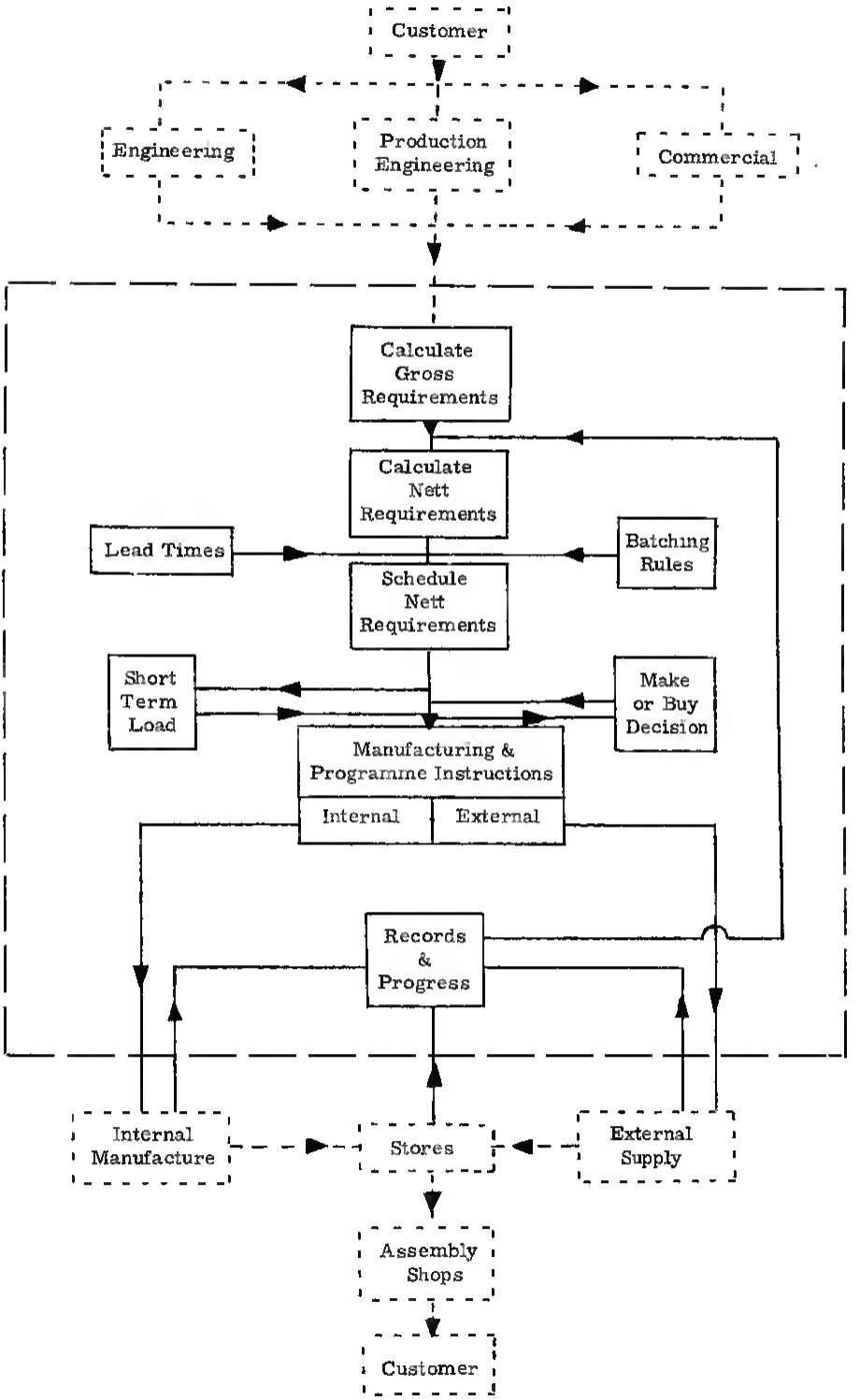

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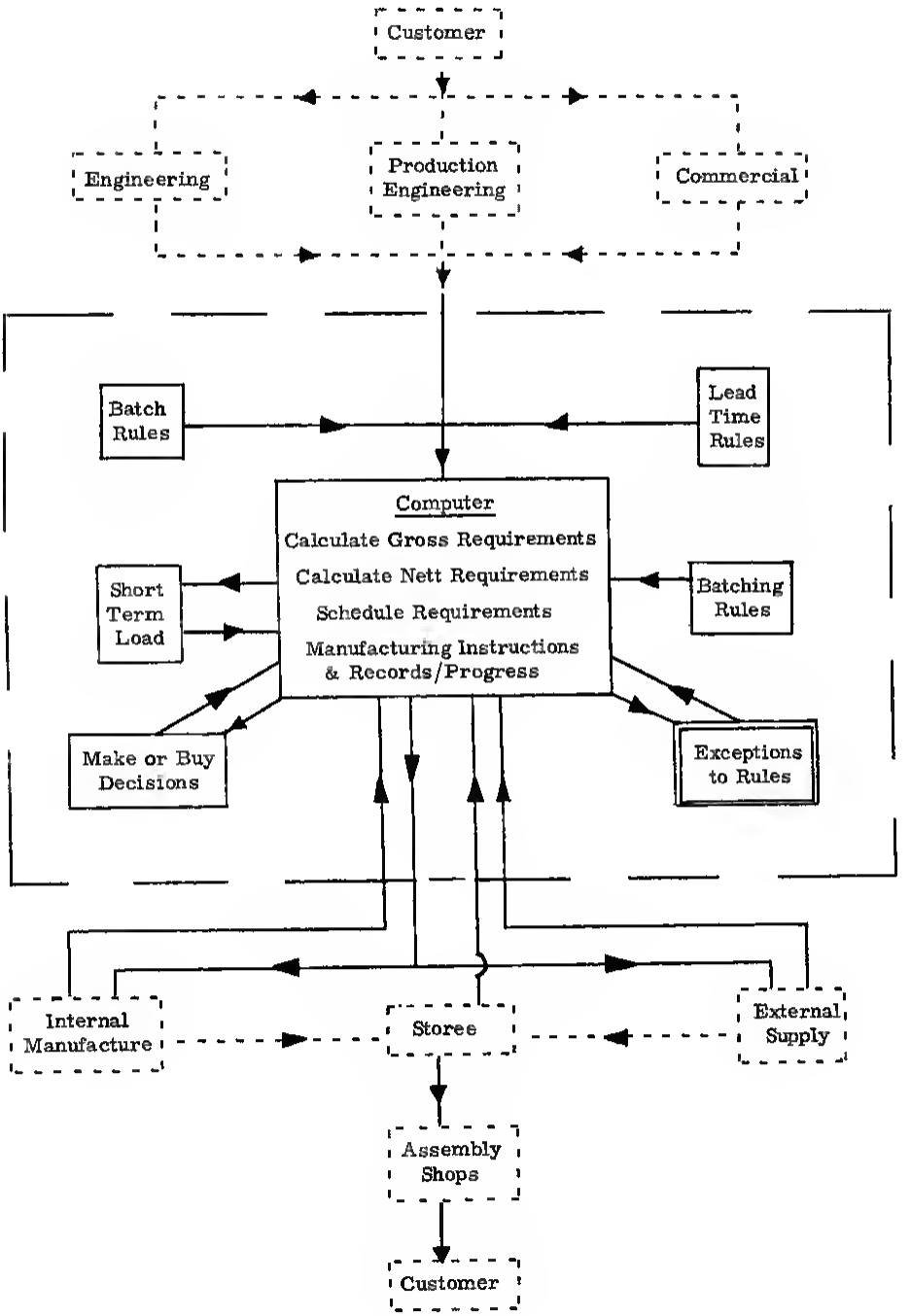
CHART 2

REPORT ON PRODUCTION CONTROL



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APPENDIX 1 TO ANNEX E

SCALE OF THE PROBLEM

	Total No. of items (excl. std. parts)	% Parts Manufactured Internally	% Parts Manufactured Externally	% Parts Manufactured on Special Plant	% of Internal Manufacture Manhours spent on Assembly	Expected qty. either Manufactured or to be Manufactured
Supersonic Interceptor Aircraft	25,000	88%	12%	Negligible	45%	200 (Approx.) (6 Batches)
Medium Size Airliner	130,000	80%	20%	Negligible	40%	75-100 (Approx.) (6 Batches)
Small Strike Aircraft	20,000	90%	10%	Negligible	47%	100 (Approx.) (4-5 Batches)
Large Engine	4,500-5,000	N/A	N/A	35%	6%	300
Small Engine	1,000	N/A	N/A	20%	4%	500

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APPENDIX 2 TO ANNEX E

TECHNICAL MODIFICATIONS

1. SCALE OF THE PROBLEM

Technical modifications may be divided into three categories to satisfy:-

(a) The requirements of the specification. Generally these apply to the development phase of the project but there is some overlap into the production period as service experience is obtained.

(b) A revision to the specification. These apply both to the development and production phases.

(c) The reduction of manufacturing costs. These normally occur in the late development and early production phases.

In order to obtain some idea of the total volume of these changes on production, three airframe projects have been analysed and the results are shown in the table at the end of this Appendix.

2. IMPACT OF MODIFICATION ON PRODUCTION CONTROL

One of the main functions of Production Control is to ensure an adequate supply of parts for assembly to the correct standard at the right time.

If all modifications were phased in such a manner as to provide adequate periods for the provisioning of tools and materials followed by the manufacture of parts in a normal priority and sequence, then apart from the difficulty of maintaining the schedules of parts required up to date this aspect would present little problem.

In fact the majority of changes, including those covering substantial alterations to specification, have to be implemented in a reduced time scale.

The effect of this is to require:-

(a) The manufacture of parts by alternative methods due to lack of production tooling.

(b) The use of alternative materials.

(c) The achievement of reduced manufacturing cycles for details.

(d) A substantial progress effort.

3. THE PRESENT POSITION

During their discussions the Working Party have established that in as far as the internal organisation of each Company is concerned, progress has been made in endeavouring to improve the overall control of modifications. While the detailed methods used vary, broadly efforts are made to balance the technical advantages of a particular change against the cost and possible delay to programme.

In addition, on new military projects, the establishment by the Ministry of Project Officers and Configuration Control Boards should undoubtedly effect a tighter degree of control.

It is, however, difficult to assess the value of these controls due to a lack of detailed statistical evidence on past projects and the problems involved in clearly segregating the costs of modifications and their effect on programme.

4. THE FUTURE POSITION

Any industry whose means are dependent on technical performance must be organised to accept and handle changes.

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From a Production Control aspect, however, it is essential that the timing of any change should provide an adequate period for introduction.

The Working Party appreciate that in this case they can only outline the magnitude of the problem in as far as it affects Production Control and it is neither within their terms of reference or capability to make specific recommendations.

However, while there is within industry a concentrated joint effort in the technical, production and commercial departments to achieve the best overall balance between the conflicting requirements, we have some doubt as to whether in the case of military projects the present organisation in the Ministries permits such a balanced review and whether in some cases changes may not be dictated by a specialist interest.

/INCIDENCE

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INCIDENCE OF MODIFICATIONS IN TYPICAL PROJECTS

Project	1st Mark		2nd Mark		3rd Mark		4th Mark		5th Mark	
	No. of a/c	No. of Mods.	No. of a/c	No. of Mods.	No. of a/c	No. of Mods.	No. of a/c	No. of Mods.	No. of a/c	No. of Mods.
Military Project	20	150	40	178	58	217	16	115	-	-
Military Project	19	550	28	87	44	132	19	104	70	244
Civil Project	24	1,300	15	476	15	62	-	-	-	-

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APPENDIX 3 TO ANNEX E

SHORT TERM PROGRAMMING

The efficiency of any Production Control System is critically dependent on the accuracy of the overall short term programming of projects.

Some of the problems of Production Control have been accentuated in recent years by increasing instability of the immediate task or programmes.

(1) Effect of Variations in Programmes on Production Control

Variations in programmes

(a) place the manufacturing shops in an out of balance condition so that without complete re-scheduling of projects, work is not performed in the correct sequence;

(b) increase the amount of day to day progress work required;

(c) result in the incorrect allocation of stocks, parts or materials;

(d) increase the amount of Work in Progress.

(2) Reasons for the Variations in Programmes

(a) The Industry

Variation in Short Term Programming occurs in industry primarily either because of delay in departments due to incorrect assessment of the capacity required for a project against that available, or alternatively because of technical changes needed to meet either the original or amended specification.

It is essential that there is accurate forward loading in all the departments concerned with a project including the Design, Production Engineering, Commercial and Production functions.

Also once a detailed programme has been agreed it must be maintained by all departments.

Production Control can only maintain a balanced production position if both Design and Production Engineering achieve their part of the programme.

In the case of Civil Projects adequate forecasting of spares requirements is essential and in this respect because of the percentage of work involved this is more significant in the Aero Engine Companies.

(b) The Customer

In the industry, although there have been mistakes up and down on forecasting for commercial projects, the major impact has arisen on military programmes. This comment is not intended to cover major cancellations but the variations in programmes which arise from a variety of specification/performance/customer requirement changes.

(3) Future Policy

The Working Party accept that this aspect is in many respects outside the Terms of Reference but because of the very considerable impact that it can have on the Production Control functions the following general observations are made:-

(a) The Industry

The Working Party believe that considerable progress has been made in the last few years in all departments in more accurately assessing short term forward forecasts and the capacity available.

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The extension of data processing in the industry, which is referred to in this report, will provide facilities to improve this aspect still further.

In addition, it is apparent that by the use of Project Control techniques a considerable impact has been made on the problem of ensuring that departments achieve their internal programmes and a more balanced control of specification changes. As further experience is obtained on overall control of projects this will improve.

Also, both the engine and airframe companies are taking steps to improve their methods of spares provisioning.

(b) The Customer

It is believed that a closer relationship between ultimate customer and industry, combined with an acceptance at a very early stage of production, by both parties, of firm but realistic cost and specification limits is essential. Often performance and other specification requirement is agreed at too late a stage of a contract/programme negotiation. Closer links with tight rigid timetables for project definition are essential.

Much of the production specification changes are technically essential, but there is too much loose definition of requirement in the early stages.

This also applies to the very large work content in a military aircraft of equipment which is under separate Ministry supply. Changes here are often a cause of programme changes.

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APPENDIX 4 TO ANNEX E

AN EXAMPLE OF RATIONALISATION

A particular example of the effect of rationalisation on organisation and production control problems may be seen by reference to the present situation in the aero-engine division of Rolls-Royce Ltd. which employ some 25,000 people directly on production work.

Some years ago the major manufacturing operations in this division were split into 5 operating units or work centres, each with an independent management structure and reasonable autonomy such as Production Engineering, Quality, Purchase etc.

The result of this experience has been a desire in the operating areas to further sub-divide the major units to form 15 or more individual product centres in the manufacturing area, each of which will be responsible for one type of product, e.g. compressor blades, gears etc.

There is no question that at the direct workshop operating level this will improve communications and operating efficiency; however, the penalty that has had to be weighed against this is the increasing complexity of the production co-ordination task.

The availability of the present and future computer control systems provides tools without which de-centralisation would not be possible, and with these tools it has been decided to proceed with this further de-centralisation despite the increasing complexity of the co-ordination.

The resulting organisational pattern in the above example indicates fairly clearly the organisational problem. After this re-organisation has been completed there will be between 15 and 20 manufacturing units providing components to two major assembly factories, and two separate spare parts organisations. In each case the end products are subject to high rates of technical and commercial change, which have already been outlined as part of the industry's business. Two separate sections of the headquarters organisation are responsible, one for the day to day co-ordination of production priorities and output, and another for the broad forward production planning and procedures.

/APPENDIX 5

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APPENDIX 5 TO ANNEX E

POLICY OF PROGRESSING EITHER TO SHORTAGES OR SCHEDULES

To achieve the supply of parts to the assembly line, a Production Control organisation operates by a combination of two approaches. These are:-

(a) Shortages

Concentration of the progressing effort on clearing the shortages of parts required either immediately prior to or during the assembly cycle.

(b) Scheduling

Concentration of the major effort on clearing parts to a planned schedule.

While historically the majority of effort has been on clearing shortages, logically the second method of approach must be more efficient than the first.

The fact that this has been the case is indicative of two points:-

(i) The planned schedule may not be phased correctly to the production requirements

(ii) The facilities available are not adequate to meet the planned schedule

The controlling factors in short term planning are dealt with elsewhere in this report but some of the factors in achieving a better balance of effort are considered in this Appendix.

1. SCALE OF THE PROBLEM

Examples of the volume of parts to be handled are given in Appendix 1.

Since it is generally accepted that at a maximum only 10% of the parts required can be controlled by direct progress action and the balance can only be obtained by the normal passage of work through the organisation, it is apparent that some improvement is required

It is therefore essential that Production Control ensure that the concentration of effort is on maintaining the planned schedule rather than on the progressing of parts at a late stage in the production cycle.

The difficulties of achieving this condition are:-

(a) The establishment of an accurate schedule giving a true priority and capable of being quickly amended to suit changing circumstances.

(b) Providing details of the plan to those responsible for implementation in a concise, accurate and up to date form which they can relate to the overall delivery programme.

(c) Measuring progress against the plan in an adequate manner to ensure that corrective action can be taken.

(d) Highlighting to the departments responsible the day to day hold-ups which may occur.

2. THE FUTURE POLICY

The major problems are the volume of parts to be handled and the changing requirements due to technical modifications. The only method by which the objective can be achieved is by managing a factory using schedule exception reports in all the departments responsible for any function in the manufacture of a part.

It is impracticable to consider substantially improving present procedures by conventional clerical methods without a disproportionate increase in staff. It is therefore necessary to consider the use of more extensive data processing systems and consideration is given to this aspect in detail in Appendix 8.

/APPENDIX 6

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APPENDIX 6 TO ANNEX E

DECISION ON BATCHING QUANTITIES

The best methods of establishing batch quantities for the manufacture of parts have been investigated continually by the industry.

Generally batch quantities have been selected overall for the project based on the production rate and this, adjusted by certain simple general rules, has been used for a wide variety of different types of parts.

Determining the batch size for issue of details against a particular contract requirement requires the consideration of a number of criteria. These are:-

(a) Economic manufacturing cost based where applicable on a combination of operating and setting times.

(b) The total capacity available. The issue of larger batches could involve the need to transfer work outside the Company in order to satisfy the total requirements for the project or series of projects.

(c) The cost of making an issue in terms of documentation and grouping of materials/tools.

(d) The cost of work in progress if manufacture of details is substantially ahead of assembly.

(e) The effect of any agreements with the operators which increase the cost of small batches.

(f) The additional cost on assembly if there is a discontinuity in the flow of parts.

(g) Effect of obsolescence.

(h) Re-work of defective items.

These aspects must be considered in relation to the effect of unplanned requirements such as scrap or urgent spares requirements which cannot be linked with a main batch.

1. THE PRESENT POSITION

Various rules have been established in industry to take account of one or more of these factors. However, it appears that so far no system has yet been established which relates the majority of these factors.

Even if such a system had been established, it would be too complex to operate using conventional clerical methods.

2. THE FUTURE POLICY

Two alternative approaches can be made.

(a) Manufacture for Stock

Consideration should be given to the manufacture of a larger range of stock items either on a consumable basis or alternatively, by increasing a contract quantity to include some allowance for spares or miscellaneous requirements.

A considerable amount of investigation is required to establish which items should be placed in this category in order to obtain a balance between the advantages from a production aspect of holding stock and the commercial expenditure involved.

/(b)

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(b) Manufacture for Commitments

The establishment and use of formulae which enable the batch provisioning of each item to be considered separately in relation to the controlling factors stated previously.

These formulae would have to incorporate a series of variables which would be amended as conditions altered in the factory. These could only be used in conjunction with a computer based data processing system in view of the complexity of the calculations.

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APPENDIX 7 TO ANNEX E

LEAD TIMES FOR MANUFACTURE

In preparing a manufacturing schedule of parts it is necessary to establish specific cycle times for sach item to cover material provisioning, tooling and manufacture which in turn can be added to the assembly times for a project programme to give the overall lead time.

This involves the estahlishment of:-

(a) The period required for assembly

(h) The point in time at which a particular component is required

(c) The manufacturing time required for the component

(d) The period required to provision both msterials and tools for the component

The time allowed for any one of these activities can be varied depending on the priority given to it.

For example, in the case of the assemhly period while certain items are essential at a given point in time on the line, in many cases there is desirsble time for svailability and a lstest possihle time.

The cycle time for the production of a detail part is seldom a factor of the manufacturing hours required unless it is particular complex and uses special purpose equipment.

Tahle 1 shows a aimplified list of ths movements which occur in s production organisation for the manufacture of a simpls component such as a bolt. It will he seen that the period of manufacturs is controlled hy the handling time rather than the manufacturing time.

To relate this to the lead time Chart 3 shows:-

(i) The overall lead time if an average cycle time is used for manufacture and the bolt is assembled at a desirsble stage.

(ii) The overall lead time if a minimum cycle time is used for manufacture and the bolt is assembled at the latest possible stage.

THE PRESENT POSITION

A compsrison of experience in the industry shows that all the Companies are concerned with this problem and considerable progress has heen msde in trying to establish lead times for manufacture.

To date, however, no complstely satisfsctory methods have heen devised for:-

(a) Defining a variahle lead time which can be altered according to the production position

(h) Providing a means of using a variable lead time

(c) Re-planning the lead times for components as conditions vary

Consequently the planning in the production control phase does not at this stage necessarily represent a practical plan on the production floor.

THE FUTURE POSITION

Currently work is procseding to varying extents to analyse this particular problem in depth.

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The results show clearly that the establishment of variable lead times and using these in an effective manner on a wide variety of parts can only be achieved with further operational research followed by the application of suitable data processing systems.

/TABLE 1

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TABLE 1

List of Movements to Manufacture a Simple Bolt.

1. Issue Instructions.
2. Allocate Material.
3. Issue Material to Shops.
4. Allocation with Tools, Drawings etc. to 1st Manufacturing Centre.
5. Allocation to Operator.
6. Queue.
7. Turn bolt and thread
8. Transfer to 2nd Manufacturing Centre.
9. Allocation to Operator.
10. Queue.
11. Mill Slot
12. Transfer to 3rd Manufacturing Centre.
13. Allocation to Operator.
14. Queue.
15. Drill Locking Holes
16. Transfer to Inspection Department.
17. Inspect and Clear.
18. Transfer to Treatment Centre.
19. Allocation.
20. Queue.
21. Cadmium Treatment
22. Allocation to Store.
23. Received at Store.
24. Booked into Stock.
25. Transfer to bin ready for issue to assembly.

An average time to manufacture this component would be in the order of 8 weeks. If required as a matter of the highest possible priority it would take one day.

/CHART 3

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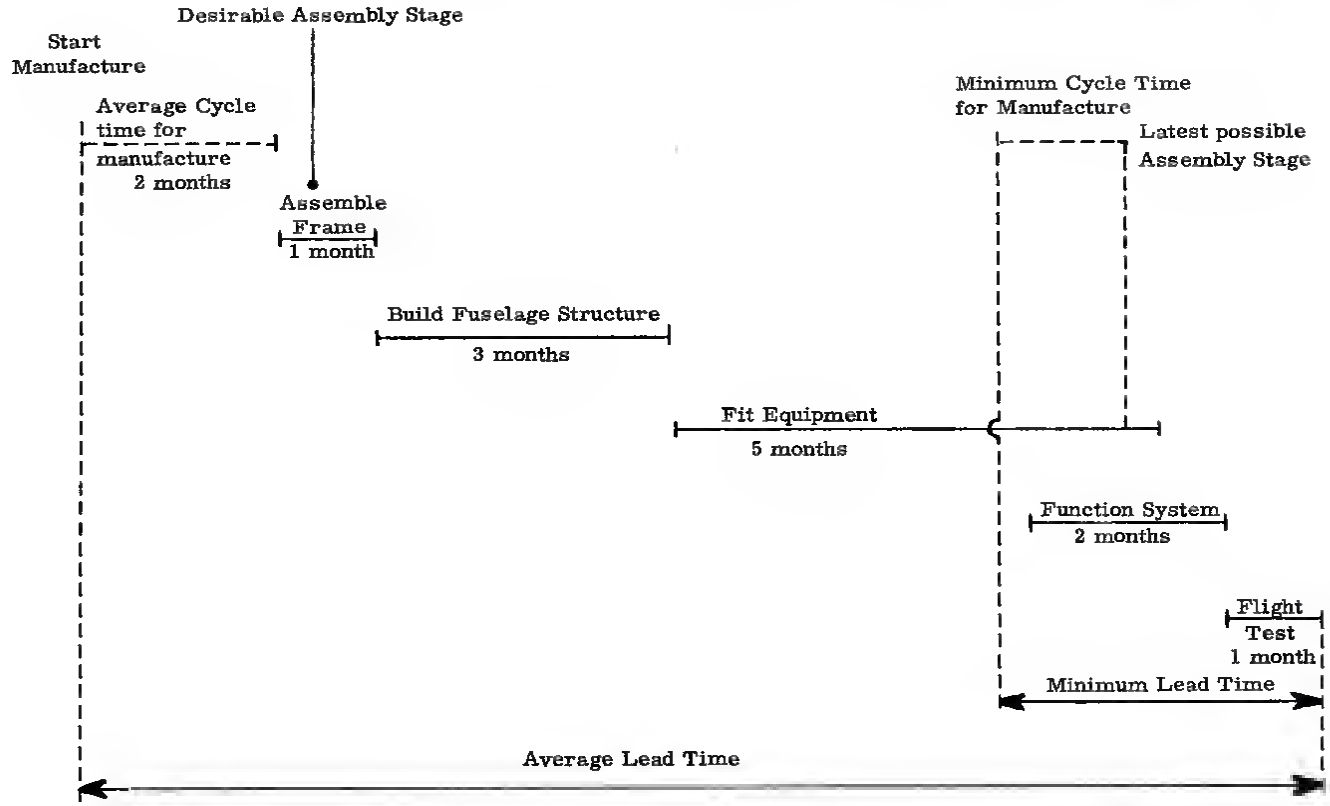
CHART 3

Lead Times for a Bolt required to Assemble a Mounting Bracket for a Hydraulic Component



/APPENDIX 8

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APPENDIX 8 TO ANNEX E

EXTENSION OF DATA PROCESSING

The previous Appendices to this report have all emphasised that the basic problems of Production Control are:-

(a) The large volume of parts to be handled.

(b) The high rate of change.

(c) The complexities involved in functions such as determination of batch sizes.

(d) The problems that arise with rationalisation in the industry.

In a number of these cases it has been stated that, in the view of the Working Party, it is not practical to consider effecting substantial improvements to the present systems without the more extensive use of Data Processing since it would be impractical to operate improved systems using conventional clerical methods.

The object of this Appendix is to show the present and future position of Data Processing in relation to Production Control.

1. THE REASONS FOR USING DATA PROCESSING

Figure 3 to this Appendix gives a broad but somewhat artificial description of the fact that effective Production Control depends upon the ability to update, inter-relate, manipulate and interrogate a number of records.

The data given in Section 3 of this report and the associated appendices confirm that the volume and rate of change of these records is so high that, even using the present limited procedures, the use of clerical labour for the handling of these records is expensive and protracted. Only by maintaining the records in a machine-processable form can one extend the present systems economically.

Also the economic advantages of computers will increase as time passes since clerical costs are rising whereas computing costs are decreasing; in any event competent clerical staff are increasingly scarce.

It is evident from Figure 3 that there is a very high degree of interdependence between many traditionally separate activities. If this diagram is extended to cover all functions of a Company it is apparent that a similar overall interdependence exists.

It follows that information held in a suitable form in a central computer may be used as a common pool of data by a number of departments for different functions. This approach has led to the idea of an 'Integrated Management Information System' or Corporate Data Bank.

Owing to the severe limitations of manually based data handling systems many of the rules associated with production have been relatively crude.

As an example, in order to allow adequate lead time for the manufacture of detailed parts, these items have in the past been placed in one of a small number of categories each of which has an associated lead time. This approach can lead to a large Work in Progress and at the same time serious shortages. Using the computer it is now possible to match the lead time to the individual component in a more precise manner.

Similarly, when attempting to decide whether or not a machine shop is able to cope with a given work load, the complexity of the problem defeats manual analysis and crude approximations have to be made. Again this results in under-utilisation of machines, and at the same time critical shortages. This problem is, of course, aggravated by the inevitable disturbances, scrap, machine breakdowns etc., which occur after the plan is issued. Again, the computer's ability to re-process the data and issue revised instructions can lead to improved machine utilisation and better scheduling.

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2. THE PRESENT POSITION ON DATA PROCESSING

To date no one company has introduced a complete computer based system covering all activities and different companies have tackled the sub-system in a different sequence.

Since the boundaries of these sub-systems are dependent upon the detailed organisation and procedures within the company, it is difficult to give a clear picture of the areas in which computers have been applied.

The National Computing Centre have recently published a report entitled "Computer Aided Production Control". In order to assess objectively the present position in the industry, a survey has been made of the operating systems against a series of sub-sections defined by the Centre in their report.

The results of this survey are shown in Table 1 to this Appendix, for forty companies from a wide cross-section of manufacturing industry. It has been extended to provide a comparison with a number of major aircraft industry companies (41-49 in the table).

The table demonstrates that by comparison with other industries in Great Britain the aircraft industry is in a leading position in the field of data processing.

In addition, the report identifies four levels of increasingly sophisticated computer applications.

(i) Education - to create a general awareness of the potential advantages.

(ii) Data Processing - to replace clerical activities.

(iii) Management Information - to provide data on which to base managerial decisions.

(iv) Optimisation - to increase the efficiency of the operations by using more complex control procedures.

Almost all current activities in the aircraft industry are at levels (ii) or (iii).

3. ECONOMIC ADVANTAGES OBTAINED FROM DATA PROCESSING.

It is impossible to give a simple quantitative indication of the economic advantages obtained from replacing manual systems by the computer. This difficulty is associated with the fact that an organisation's work load has changed markedly during the period concerned thus preventing a valid comparison. Often too, the advantage is expressed in terms of the time saved to carry out a task. As an example, Rolls-Royce can now re-schedule their production within days of the receipt of a new order whereas previously it took months to do this, but it is difficult to convert this improvement into economic terms.

This difficulty in no way lessens the universal view at all levels of Management that the industry must increase its investment in computer based systems.

It is relevant to note that members of the Working Party have found that the difficulty in identifying the specific advantages is also experienced in the U. S. aerospace industry.

The undoubted advantages offered can only be realised after considerable expenditure of time and money. Annual expenditure on computers and associated staff is now running at 1% to 2% of turnover and this figure should be compared to the U.S.A. figure of 2-3%.

4. CONTROLLING FACTORS IN THE INTRODUCTION OF DATA PROCESSING

It is well known that industry in the United Kingdom has not adopted computer systems as rapidly as the United States and this is sometimes accepted as simply another manifestation of our more conservative approach to any innovation. It is necessary to identify a few major factors which have slowed down this particular development.

/(a) Systems

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(a) Systems, Design and Implementation

The design of systems which are sufficiently flexible to permit rapid modification in the light of operating experience and at the same time able to deal with the inevitable errors which arise, has proved much more difficult than was generally assumed a few years ago.

Many of the earlier applications suffered from a failure to view these as part of a larger system. As a result the interface between the sub-systems was often ill chosen and this slowed down their development. In general, computer systems offer obvious advantages in dealing with large volumes of data and in many organisations these have been exploited . In principle the computer ought to offer equal advantages over manual systems where there is a high rate of change but in practice it has proved difficult to realise these potential advantages.

The effort involved in developing and installing a computer based production control system is largely independent of the production rate or the length of the production run. It follows that it is increasingly difficult to justify such systems as the volume of production decreases.

(b) Education

Over and above the need for trained specialist programmers and systems analysts, the successful introduction of computer-based systems requires the informed support of all levels of the 'user' organisation; from the manager who must play a key part in defining the system to the operator who must feed back accurate and timely data. All organisations express surprise at the time required to ensure that apparently trivial and self-evident ideas are well understood.

The initial developments in the industry were generally under the control of specialist data processing departments, due partly to the fact that Companies were in the first phases of the operation and this led to systems which were not necessarily practical for the line departments.

This was perhaps inevitable in the initial 'selling' period but it is now widely recognised that rapid exploitation of the computer's potential can only be achieved if the responsibility is at least shared by the users of the system's output.

(c) Computer Technology

Broadly the majority of development in the industry to date has been carried out on what is loosely termed second generation equipment.

One of the basic requirements of Production Control is that certain records must be maintained up to date and data made available frequently. While second generation equipment is able to handle large volumes of data it is difficult, with a high rate of change, to update these records with sufficient frequency to meet all requirements.

Linked with this is the question of the computer manufacturers' executive/operating programmes which were often inflexible and late in terms of availability. This also applies at present to work started on some of the third generation equipment.

5. FUTURE DEVELOPMENTS

(a) Systems, Design and Implementation

All the Companies represented on the Working Party recognise the importance of linking together the various sub-systems which have been developed and operating a data bank for use by all departments. Much effort is being devoted to designing sub-systems in a modular form so as to facilitate this linking process.

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In an effort to reduce the cost of systems development, companies in the industry have developed or are developing common systems for use across all their main factories.

In all three Companies the responsibility for systems has moved to the point where the user group initiate and largely control any developments of the system. Under this type of control there is a greater assurance that a proper cost/benefit assessment has been made.

(b) Education

All three Companies now operate intensive training and education schemes not only for specialists but also for all levels of management. It is expected that this arrangement will result in line management taking an increasing interest in the specification of the system.

(c) Computer Technology

The introduction of third generation equipment should have a significant effect on the position.

The new types of equipment are faster in operation and provide direct access disc storage. In addition, Data Collection equipment can be used to relay movements or decisions direct to the computer so that all records are up-to-date.

Provided this equipment is backed by an adequate and flexible service in terms of executive and operating programmes the developments in the next few years are likely to be controlled more by the availability of people than equipment.

It should be noted that all of the organisations concerned with this report have planned to increase their expenditure over the next three to five years to in the order of 2%-3% of turnover.

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TABLE 1 APPENDIX 8

Company 1–16

Key Ref	Activity Sub-Heading	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A (i)	Order Entry	●	—	●	—	—	—	●	—	●	●	—	●	—	●	●	●
(ii)	Order entry with pre-invoicing	—	—	—	—	●	—	—	●	—	—	—	—	●	—	—	—
(iii)	Order entry with post-invoicing	—	—	—	—	—	—	●	—	—	—	—	—	—	—	—	—
B (i)	Single historic stock recording	—	—	—	—	—	—	●	—	●	—	●	—	—	●	—	—
(ii)	Re-order point control	—	●	●	●	—	●	—	—	—	—	—	—	●	●	—	—
(iii)	As B (ii) with forward allocations	—	—	—	—	—	—	—	—	—	—	—	—	—	●	●	●
(iv)	As B (ii) with demand forecasting	—	—	—	—	●	—	—	—	—	—	—	—	—	—	—	—
(v)	As B (iv) with forward allocations	—	—	—	—	—	—	—	●	—	—	—	—	—	—	—	—
(a)	Finished goods stock	—	—	●	—	●	●	—	●	—	—	—	—	●	●	—	●
(b)	Intermediate part stock	—	●	●	●	—	●	●	●	—	—	●	—	—	●	●	●
(c)	Bought out good stock	—	●	●	●	—	●	●	●	—	—	●	—	—	●	●	●
(d)	Raw materials stock	—	●	●	—	—	—	●	●	—	—	—	—	—	●	—	●
C (i)	Gross demand break down for one project	—	—	—	—	—	●	—	—	—	—	—	—	—	—	—	—
(ii)	Gross demand break down for all projects	—	—	—	—	—	—	●	—	—	—	●	●	—	—	—	—
(iii)	Nett demand break down	—	—	—	●	—	—	—	—	—	—	●	—	—	—	—	—
(iv)	Nett demand break down with econ. batching	●	●	●	—	—	—	—	●	—	—	—	—	—	—	●	●
(a)	For one time period only	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(b)	For all time periods ahead	●	●	●	●	—	●	●	●	—	—	●	●	—	—	●	●
D (i)	Total load forward plan	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(ii)	Load centre forward plan	—	—	●	—	●	●	●	●	—	●	●	●	—	●	—	●
(a)	Blanket load statement	—	—	●	—	—	●	—	●	—	●	—	—	—	—	—	—
(b)	Detailed job statement	—	—	—	—	●	—	●	—	—	—	●	●	—	●	—	●
E (i)	Shop load centre job list	●	●	●	—	—	●	●	—	●	—	—	—	●	●	●	●
(ii)	Load centre job with priorities	—	—	—	●	●	—	—	●	—	—	●	—	—	●	—	—
(iii)	Detailed shop loading	—	—	—	—	—	—	—	—	●	—	—	●	—	●	—	—
F (i)	Single project critical path scheduling	—	—	—	—	—	—	—	—	—	—	—	—	—	●	—	—
(ii)	Multi project critical path scheduling	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(a)	Without resource allocation	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(b)	With resource allocation	—	—	—	—	—	—	—	—	—	—	—	—	—	●	—	—
G (i)	Instruction schedules	—	—	—	—	●	—	●	●	●	—	●	—	●	●	—	—
(ii)	Instruction to document printers	●	●	—	●	—	●	—	●	—	—	—	—	—	—	●	—
(iii)	Computer printed job tickets	—	—	—	—	—	●	●	—	—	●	—	●	●	●	—	●
H (i)	Feedback from manual recorded documents	●	●	●	●	●	●	●	●	—	—	●	—	●	●	—	●
(ii)	Use of computer prepared documents	—	●	—	—	—	●	—	—	●	—	●	—	●	●	●	●
(iii)	Automatic data-collection	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
J (i)	WIP bulk load recording	—	—	—	—	●	—	—	—	—	—	—	—	—	—	—	—
(ii)	WIP job recording	—	●	—	—	—	—	●	●	●	—	—	—	—	●	—	●
(iii)	WIP component recording	●	●	●	●	—	●	●	●	●	—	●	—	—	—	—	●
(a)	Key control stages	●	●	—	—	●	—	—	●	●	—	—	—	—	●	—	●
(b)	Every operation	—	—	●	●	—	●	●	—	—	—	●	—	—	—	—	—
(c)	Complete schedule	—	—	—	●	●	—	—	●	●	—	—	—	—	—	—	●
(d)	Exception reporting	—	—	●	—	—	●	●	—	—	—	—	—	—	●	—	—
K (i)	Progress on bought out goods	●	—	●	●	—	—	—	●	—	—	●	—	—	●	●	●
(ii)	Progress on subcontracted work	—	—	●	●	—	—	—	●	—	—	—	—	—	—	●	●
(iii)	Progress on raw materials	●	—	●	●	—	—	—	●	—	—	—	—	—	●	—	●
L (i)	Analysis of labour utilisation	—	—	—	●	—	●	●	—	—	—	●	—	—	●	—	—
(ii)	Analysis of plant utilisation	—	—	—	●	—	●	—	—	—	—	—	—	—	●	—	—
(iii)	Analysis of scrap utilisation	—	—	—	●	—	—	—	—	—	—	—	—	—	●	—	—
M (i)	Job costing	—	—	—	—	—	—	●	—	—	—	—	—	—	●	—	—
(ii)	Standard costing with department variances	—	●	—	—	—	—	—	●	—	—	●	—	—	●	●	●
(iii)	Standard costing with detail variances	—	—	—	●	—	—	—	—	—	—	—	—	—	●	—	—
ACTIVITY TOTALS		7	7	8	8	7	8	10	10	4	3	10	8	5	11	8	10

Company 17–32

Key Ref	Activity Sub-Heading	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
A (i)	Order Entry	●	—	—	—	—	●	●	—	●	—	●	—	—	—	—	—
(ii)	Order entry with pre-invoicing	—	—	—	—	●	—	—	—	—	—	—	—	—	—	—	—
(iii)	Order entry with post-invoicing	—	—	●	—	—	—	—	—	—	—	—	—	●	●	—	●
B (i)	Single historic stock recording	●	—	●	—	—	—	—	—	●	—	—	—	●	—	—	●
(ii)	Re-order point control	—	—	—	—	—	—	—	—	—	—	●	●	—	●	●	—
(iii)	As B (ii) with forward allocations	—	●	—	—	—	—	—	—	●	●	—	—	—	—	—	—
(iv)	As B (ii) with demand forecasting	—	—	—	—	●	—	—	—	—	—	—	—	—	—	—	—
(v)	As B (iv) with forward allocations	—	—	—	—	—	●	●	—	—	—	—	—	—	—	—	—
(a)	Finished goods stock	—	—	●	—	●	—	—	—	—	●	—	●	●	—	—	●
(b)	Intermediate part stock	●	●	—	—	—	●	●	—	●	●	●	●	●	●	—	—
(c)	Bought out good stock	●	●	—	—	●	●	●	—	●	●	●	●	●	●	●	●
(d)	Raw materials stock	●	●	—	—	●	—	●	—	—	—	●	●	●	●	●	●
C (i)	Gross demand break down for one project	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(ii)	Gross demand break down for all projects	—	—	—	—	—	—	—	—	●	●	—	—	—	—	●	—
(iii)	Nett demand break down	●	—	●	—	—	●	—	—	—	—	—	—	●	—	—	—
(iv)	Nett demand break down with econ. batching	—	—	—	—	●	—	●	—	—	—	●	●	—	—	—	—
(a)	For one time period only	—	—	—	—	●	●	—	—	—	—	—	—	●	—	●	—
(b)	For all time periods ahead	●	—	●	—	—	—	●	—	●	●	●	●	—	—	—	—
D (i)	Total load forward plan	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(ii)	Load centre forward plan	●	●	—	●	●	—	—	—	—	●	—	●	●	●	—	—
(a)	Blanket load statement	●	●	—	●	—	—	—	—	—	●	—	●	—	●	—	—
(b)	Detailed job statement	—	●	—	—	●	—	—	—	—	—	—	—	●	—	—	—
E (i)	Shop load centre job list	●	—	—	●	●	●	—	—	—	—	—	●	●	●	●	—
(ii)	Load centre job with priorities	—	—	—	—	—	—	●	—	—	—	●	—	—	—	—	—
(iii)	Detailed shop loading	—	●	—	—	—	—	—	—	—	—	—	—	—	—	—	●
F (i)	Single project critical path scheduling	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(ii)	Multi project critical path scheduling	—	—	—	●	—	●	—	—	—	—	—	—	—	—	—	—
(a)	Without resource allocation	—	—	—	—	—	●	—	—	—	—	—	—	—	—	—	—
(b)	With resource allocation	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
G (i)	Instruction schedules	●	●	—	—	●	●	—	—	—	—	—	●	●	—	●	●
(ii)	Instruction to document printers	●	—	—	—	—	—	●	—	—	●	●	—	●	●	●	—
(iii)	Computer printed job tickets	—	—	—	—	—	—	—	●	●	—	—	●	●	—	—	—
H (i)	Feedback from manual recorded documents	●	●	●	—	●	●	●	—	—	●	●	●	●	—	●	—
(ii)	Use of computer prepared documents	—	—	—	—	—	—	—	●	—	●	—	—	●	●	●	—
(iii)	Automatic data-collection	—	—	—	—	—	—	—	—	—	—	—	—	●	—	—	—
J (i)	WIP bulk load recording	—	—	—	—	—	—	—	●	—	—	—	—	—	—	—	—
(ii)	WIP job recording	●	—	—	—	—	●	●	●	—	—	—	—	—	●	—	—
(iii)	WIP component recording	●	●	—	—	—	—	●	●	—	—	—	●	●	●	●	—
(a)	Key control stages	—	—	—	—	—	●	●	—	—	—	—	—	●	●	—	—
(b)	Every operation	●	●	—	—	—	—	—	●	—	—	—	●	—	—	●	—
(c)	Complete schedule	●	●	—	—	—	●	—	●	—	—	—	—	—	●	●	—
(d)	Exception reporting	—	—	—	—	—	—	●	—	—	●	—	—	●	—	—	—
K (i)	Progress on bought out goods	●	●	—	—	—	●	●	—	—	●	—	—	●	●	—	—
(ii)	Progress on subcontracted work	—	●	—	—	—	—	—	—	—	●	—	—	●	—	—	—
(iii)	Progress on raw materials	—	●	—	—	—	●	●	—	—	—	—	—	●	—	—	—
L (i)	Analysis of labour utilisation	—	●	—	—	—	—	—	—	—	—	●	—	—	●	—	—
(ii)	Analysis of plant utilisation	●	●	—	—	—	—	—	—	—	—	●	●	—	—	—	—
(iii)	Analysis of scrap utilisation	—	●	—	—	—	—	—	—	●	—	●	—	—	—	—	—
M (i)	Job costing	●	●	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(ii)	Standard costing with department variances	—	—	—	—	—	—	—	—	—	—	—	—	●	●	—	—
(iii)	Standard costing with detail variances	—	—	●	—	—	—	—	—	●	—	●	—	—	—	●	—
ACTIVITY TOTALS		11	9	5	3	7	9	8	3	4	7	8	8	10	10	7	4

Company 33–49

Key Ref	Activity Sub-Heading	33	34	35	36	37	38	39	40	Sub-Heading Totals	Main Heading Totals	41	42	43	44	45	46	47	48	49
A (i)	Order Entry	—	—	—	—	—	—	—	—	14	26	—	—	●	●	●	I	●	—	2
(ii)	Order entry with pre-invoicing	—	—	—	—	●	—	—	—	5		—	—	—	—	—	—	—	—	—
(iii)	Order entry with post-invoicing	—	●	—	●	—	●	—	—	8		●	0	—	—	—	—	—	—	—
B (i)	Single historic stock recording	—	●	—	●	—	—	●	●	13	33	●	●	●	—	●	2	●	2	—
(ii)	Re-order point control	—	—	—	—	●	—	—	●	13		—	—	—	—	●	I	●	I	—
(iii)	As B (ii) with forward allocations	—	—	—	—	—	●	—	—	7		—	—	—	I	●	I	●	I	—
(iv)	As B (ii) with demand forecasting	—	—	—	—	—	—	—	—	3		—	—	—	—	●	—	●	—	—
(v)	As B (iv) with forward allocations	—	—	—	—	—	—	—	—	3		●	—	—	—	●	—	●	—	—
(a)	Finished goods stock	—	—	—	●	●	●	●	●	10		—	—	—	I	●	—	●	—	—
(b)	Intermediate part stock	—	●	—	—	●	●	●	●	25		—	—	●	I	●	—	—	2	—
(c)	Bought out good stock	—	—	—	●	—	●	—	●	34		●	—	●	I	●	●	●	2	—
(d)	Raw materials stock	—	—	—	●	●	●	—	●	30		●	●	●	I	●	●	●	—	—
C (i)	Gross demand break down for one project	—	—	—	—	—	—	—	—	1	27	—	0	—	—	●	●	●	2	●
(ii)	Gross demand break down for all projects	—	●	—	—	—	—	—	—	7		I	—	●	—	●	2	●	—	—
(iii)	Nett demand break down	—	—	—	—	—	●	—	—	7		—	—	●	—	●	—	●	—	2
(iv)	Nett demand break down with econ. batching	—	—	—	—	●	—	●	●	13		I	—	—	—	●	I	I	—	2
(a)	For one time period only	—	●	—	—	—	●	●	●	8		—	0	—	—	—	—	—	2	—
(b)	For all time periods ahead	—	—	—	—	●	—	—	—	10		I	—	●	—	●	●	●	—	●
D (i)	Total load forward plan	—	—	—	—	—	—	—	—	8	22	●	—	—	—	●	—	I	2	I
(ii)	Load centre forward plan	●	—	—	—	—	●	●	●	22		—	0	●	●	2	●	●	2	I
(a)	Blanket load statement	—	—	—	—	—	●	—	—	11		●	—	●	●	●	—	I	2	I
(b)	Detailed job statement	●	—	—	—	—	—	—	●	11		—	0	—	●	2	●	●	2	—
E (i)	Shop load centre job list	●	—	—	—	—	●	●	●	22	31	—	0	●	—	●	●	●	2	2
(ii)	Load centre job with priorities	●	—	—	—	—	—	—	—	8		I	—	●	—	—	●	●	2	—
(iii)	Detailed shop loading	—	—	—	—	—	—	—	—	5		—	—	I	—	●	—	●	2	—
F (i)	Single project critical path scheduling	●	—	—	—	—	—	—	—	3	5	●	0	—	●	—	●	●	2	—
(ii)	Multi project critical path scheduling	—	—	●	—	—	—	—	—	3		—	—	—	I	—	—	—	—	—
(a)	Without resource allocation	●	—	—	—	—	—	—	—	2		●	0	—	●	—	—	●	—	—
(b)	With resource allocation	—	—	—	—	—	—	—	—	1		—	—	—	I	—	I	—	2	—
G (i)	Instruction schedules	●	●	—	—	—	●	●	●	20	33	—	—	●	—	●	●	●	—	2
(ii)	Instruction to document printers	—	—	—	—	—	—	—	—	12		—	0	●	—	2	2	●	—	—
(iii)	Computer printed job tickets	—	—	—	—	—	—	—	—	11		—	—	I	—	2	I	I	—	—
H (i)	Feedback from manual recorded documents	—	●	—	●	—	●	●	●	28	32	●	●	●	●	●	—	●	●	2
(ii)	Use of computer prepared documents	●	—	—	—	—	—	—	—	13		—	—	—	—	●	●	●	2	—
(iii)	Automatic data-collection	—	●	—	—	—	—	—	—	7		I	—	I	—	2	I	I	2	—
J (i)	WIP bulk load recording	—	—	—	—	—	—	—	—	3	27	—	—	—	—	—	—	—	—	—
(ii)	WIP job recording	●	—	—	—	—	—	—	—	13		●	—	●	●	2	—	●	2	—
(iii)	WIP component recording	—	—	—	●	—	●	●	●	22		—	●	●	—	●	●	I	—	●
(a)	Key control stages	—	—	—	—	—	—	●	●	13		—	●	—	—	●	—	●	—	—
(b)	Every operation	—	—	—	●	—	—	—	—	11		●	—	●	●	2	●	●	2	—
(c)	Complete schedule	—	—	—	—	—	—	●	—	13		—	●	●	●	—	●	●	2	—
(d)	Exception reporting	—	—	—	—	—	●	—	●	9		●	—	—	—	●	●	●	2	—
K (i)	Progress on bought out goods	●	—	—	—	—	●	—	—	17	17	I	—	●	—	●	2	I	●	●
(ii)	Progress on subcontracted work	●	—	—	—	—	●	—	—	10		—	—	●	—	●	—	I	—	●
(iii)	Progress on raw materials	●	—	—	—	—	●	—	—	12		—	—	—	—	●	I	I	—	●
L (i)	Analysis of labour utilisation	—	—	—	—	—	●	—	●	10	15	●	—	—	●	●	●	●	I	—
(ii)	Analysis of plant utilisation	—	●	—	—	—	●	—	—	9		—	●	●	—	—	—	●	—	—
(iii)	Analysis of scrap utilisation	—	—	—	●	—	●	—	—	7		—	—	—	—	—	2	—	—	—
M (i)	Job costing	—	—	—	●	—	—	—	—	5	20	●	●	●	●	●	●	●	●	●
(ii)	Standard costing with department variances	—	—	—	●	—	●	●	●	12		—	—	—	—	●	—	I	I	—
(iii)	Standard costing with detail variances	—	—	—	—	—	—	—	—	4		—	—	—	—	●	—	I	I	—
ACTIVITY TOTALS		7	6	1	4	3	11	8	9			8	5	11	7	11	10	11	3	4

LEGEND

● = IN USE

0 = IMPLEMENTED BUT NOT IN CURRENT USE

I = UNDER DEVELOPMENT

2 = IMPLEMENTED IN CERTAIN AREAS

— = NOT STARTED

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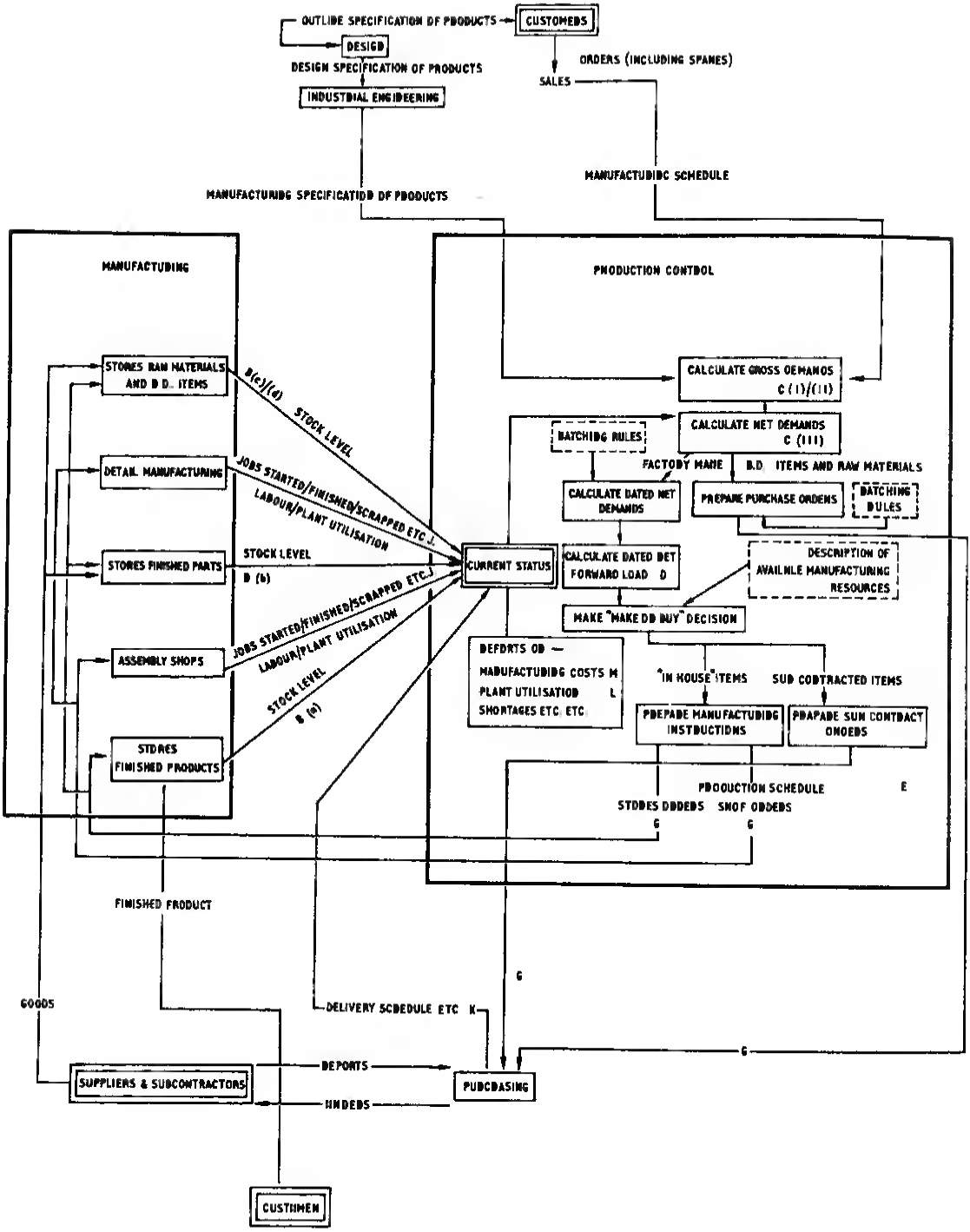

FIG. 3

THE ROLE OF COMPUTERS IN PRODUCTION CONTROL

FOR EXPLANATION OF SYMBOLS A...M SEE TABLE I

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